

A ROADMAP FOR PIER RESEARCH ON METHODS TO ASSESS AND MITIGATE IMPACTS OF WIND ENERGY DEVELOPMENT ON BIRDS AND BATS IN CALIFORNIA

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

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For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-5164.

Table of Contents

PREFACE	iii
ABSTRACT	ix
EXECUTIVE SUMMARY	1
CHAPTER 1: Issue Statement.....	7
CHAPTER 2: Public Interest Vision	9
CHAPTER 3: Background.....	11
Pre-Permitting Studies	11
Bird Interactions with Wind Turbines.....	11
Bat Interactions with Wind Turbines.....	18
Effect of New Turbine Technology on Risk for Birds and Bats	23
Assessing Indirect Impacts on Birds	27
Assessing Indirect Impacts on Bats.....	28
Assessing Population Impacts for Birds and Bats.....	29
Post-Construction Monitoring/Measuring Effects of Operations	31
Size of Search Area	32
Frequency of Searches and Scavenger Removal Bias	32
Background Mortality	34
Searcher Efficiency	35
Formulae for Correcting Carcass Counts.....	36
Metrics for Fatality Estimates	37
Impact Avoidance and Mitigation.....	38
Alerting and Deterring Mechanisms	38
Operations Modifications.....	40
Habitat and Prey Abundance Modifications	41
Compensatory Mitigation	42
The PIER Focus.....	43
CHAPTER 4: Research Needs	45
Bird Survey Techniques	45
Species-Specific Vulnerability to Collisions and Population Impacts.....	46
Habitat, Species, and Resource Development Land-Use Mapping	47
Effects of Turbine Design and Site Characteristics on Fatalities	48

Nocturnal Survey Techniques and Correlates of Risks for Bats/Birds	48
Post-Construction Fatality Monitoring	50
Bat Auditory Deterrents and Operations Modification.....	51
Buffer Zones for Birds and Bats	52
Assess Effectiveness of Compensatory Mitigation.....	52
CHAPTER 5: Goals	53
Short-Term Objectives	54
Assess Effect of Variations in Diurnal Bird Survey Techniques on Fatality Estimates	54
Evaluate Behavioral Differences between Species/Species Groups That Affect Collision Risk.....	55
Assess Potential Population-Level Effects of Wind Energy Development on Birds and Bats.....	55
Assess Effects of Repowering on Bird and Bat Fatalities	56
Evaluate Effect of Turbine Micro-Siting on Bird and Bat Fatality Rates.....	56
Activities	56
Assess Nocturnal Survey Techniques and Correlates of Collision Risk.....	56
Assess How Variations in Search Area and Search Frequency Affect Accuracy of Carcass Counts.....	57
Evaluate How Variation in Scavenging Trials Affects Accuracy of Carcass Counts.....	58
Evaluate Fatality Adjustment Equations Used to Correct Biases From Scavenging and Searcher Error	58
Investigate Effectiveness of Auditory Bat Deterrents	59
Assess Effectiveness of Operations Modifications on Bat Behavior and Fatalities	59
Evaluate Effectiveness of Buffer Zones in Reducing Impacts to Birds and Bats	59
Long-Term Objectives	60
Develop Bird and Bat Fatality Estimates at California Wind Resource Areas and Determine Pre-Permitting Correlates of Risk	60
Develop Species/Habitat Maps for California Wind Resource Areas.....	60
Conduct Studies to Assess Cumulative Population Impacts	61
Assess Effectiveness of Compensatory Mitigation Approaches.....	61
CHAPTER 6: Leveraging R&D Investments.....	63
CHAPTER 7 Areas Not Addressed by This Roadmap.....	65
Comparative Generation Technology Alternatives Analysis.....	65
Impacts to Habitat.....	65
Impact of Small-Scale Turbines.....	65
Offshore Wind Energy Development.....	66

Collision Sensors	66
Decision Frameworks	66
CHAPTER 8: References	67
CHAPTER 9: Glossary	83
List of Acronyms	83
Definition of Terms	83
APPENDIX A INDIVIDUALS AND ORGANIZATIONS CONTACTED DURING ROADMAP DEVELOPMENT	1
APPENDIX B SCIENTIFIC NAMES OF BIRDS AND MAMMALS MENTIONED IN TEXT	1

List of Tables

Table 1: Raptor Use and Raptor Fatalities at Wind Resource Areas (modified from CEC and CDFG 2007)	14
Table 2: Estimates of Bat Fatalities at Wind Facilities in North America (modified from Arnett et al. 2007)	19
Table 3: Bat Species Potentially at Risk of Collision with Wind Turbines in California (modified from CBWG 2006)	20

Abstract

This roadmap summarizes the status of research on the impacts of wind energy development on birds and bats and recommends studies to improve methods for assessing and reducing these impacts in California. Priority short-term research topics include studies to assess effects of variations in diurnal bird survey techniques on fatality estimates; behavioral differences between species/species groups that affect collision risk; population-level effects of wind energy development on California's birds and bats; effects of repowering on bird and bat fatalities; nocturnal survey techniques and correlates of collision risk; how variations in search area, frequency, scavenging trials, and fatality correction equations affect accuracy of carcass counts; effectiveness of auditory deterrents and operations modifications on bat fatalities; and effectiveness of buffer zones in reducing impacts to birds and bats. Long-term research goals include a meta-analysis of pre-permitting and operations fatality data to develop a range of fatality estimates for birds and bats for wind resource areas throughout California; creation of an interactive map/database that could show bird and bat migratory movements and ecologically important/sensitive habitats in relation to wind resources and land use; and assessing effectiveness of compensatory mitigation in offsetting impacts to birds and bats.

Keywords: Wind turbines, wind energy development, bat fatality, bird fatality, avian collisions, research, carcass count, California

Executive Summary

Wind turbine-wildlife interactions have been the subject of study for more than 20 years, but many uncertainties remain as to the best methods for assessing and minimizing the effects of wind energy development on birds and bats. This roadmap summarizes the current state of knowledge on the impacts of wind energy on birds and bats, and describes research that will improve the biological assessment, mitigation, and monitoring of wind energy projects in California.

The roadmap reflects input from a public workshop held in November 2006, as well as interviews with researchers, wind industry representatives, resource agency personnel, and other parties with interest and expertise in wind-energy/wildlife research. This document builds upon the recommendations and analysis discussed in Public Interest Energy Research Program's (PIER) first wind-wildlife roadmap (Sternner 2002). Like its predecessor, this updated roadmap is designed to help scientists set research priorities and help project evaluators steer funds toward the most pressing topics.

The recommended research topics, listed below, are focused on securing information that will establish a better linkage of pre-permitting data on site characteristics and bird/bat use with actual bird/bat impacts during turbine operation, and using this information to reduce those impacts.

Short-Term Research

The short-term (1–3 years) objectives described in this roadmap include the following topics:

- **Assess effect of variations in diurnal bird survey techniques on fatality estimates.** Compare pre-permitting data and monitoring results from wind energy projects in California and elsewhere to determine how variations in pre-permitting study design, survey techniques, and survey duration affect pre-permitting estimates of relative abundance and risk for diurnal birds. This assessment will inform which techniques are consistently the most cost-effective and useful for estimating collision risk throughout the state's wind resource areas.
- **Analyze behavioral differences between species/species groups that affect collision risk.** Analyze existing data sets to determine which California bird and bat species or species groups (for example, raptors, tree-roosting migratory bats) are consistently prone to collisions and the behavioral correlates of that risk. Conduct field studies to verify hypotheses about consistent patterns of risky behavior for species or species groups.
- **Investigate potential population-level effects of wind energy development on California's birds and bats.** Identify which special-status bird and bat species in California might experience significant population declines from wind energy development. Using monitoring reports and the published literature, quantify the known mortality factors and rates for species potentially at risk of population-level

declines and assess the potential added influence of increased fatalities from wind energy development.

- **Evaluate the effects of repowering on bird and bat fatalities.** Analyze pre-permitting and operations data collected from new and old turbines at wind resource areas that have data sets from both turbine types to better understand how repowering affects fatality rates of bat and bird species.
- **Evaluate the effect of turbine micro-siting on bird and bat fatality rates.** Using information from wind resource areas with new-generation turbines, conduct a meta-analysis of fatality data in relation to turbine configuration/topography. Determine if consistent patterns exist that could apply to micro-siting decisions at wind resource areas in California.
- **Evaluate nocturnal survey techniques and correlates of collision risk for bats and nocturnal birds.** Determine what combination of sensing techniques (such as acoustic sampling, mobile radar units, Doppler radar, thermal infrared imaging, dawn and dusk surveys) provide the most reliable data set on the occurrence of bats and nocturnal birds and which will ultimately be useful and cost-effective in estimating collision risk. Examine existing data from Doppler radar stations within and near California to look for consistent patterns of movements of nocturnal migrants that might be useful in predicting risk to bird and bat populations.
- **Assess the predictive value of bat survey techniques in estimating bat fatalities.** Determine if indices of pre-permitting bat activity can be used to predict post-construction bat fatalities at proposed wind energy facilities in California. The goal would be to determine the level and patterns of activity of different species groups of bats using the proposed wind facility prior to turbine construction, to correlate bat activity with weather and other environmental variables, and to use this information to develop the most cost-effective methods for assessing and reducing impacts to bats.
- **Assess how variations in search area and search frequency affect accuracy of carcass counts.** Undertake field studies at existing wind facilities to determine how variations in search area and frequency affect the accuracy of carcass counts. Analyze field study results in the context of fatality data from existing wind resource areas to determine the search area and interval that provides the most cost-effective, accurate carcass count. Conduct daily carcass searches at wind facilities and conduct simulations with the resulting data to determine the search frequency that provides an acceptably accurate, cost-effective carcass count.
- **Evaluate how variation in scavenging trials affects accuracy of carcass counts.** Undertake experimental field studies to determine how accurately scavenging trials reflect actual carcass removal. The field studies should assess how the deployment and characteristics of the surrogate carcasses affect the detectability and appeal of carcasses to scavengers and searchers, if scavenger removal rates are consistently predicted by body size or taxa, and if fatality monitoring can be designed to account for the ability of vertebrate scavengers to learn foraging routes at wind resource areas.

- **Evaluate fatality adjustment equations used to correct biases from scavenging and searcher error.** Assess the inherent biases of the formulae that have been used to correct for searcher error, scavenging, and other sources of bias. Recommend methods to accurately account for searcher detection error and scavenger removal of carcasses in the fatality. Test mathematical approaches for estimating the true fatalities under conditions in which the true mortality is known and assess methods for estimating the error in the resulting estimates.
- **Assess effectiveness of bat auditory deterrents and operations modifications in reducing bat fatalities.** Collaborate with other researchers in lab and field studies of auditory deterrents (high-intensity ultrasound) to assess their effectiveness in reducing collision risk for bats at California wind resource areas.
- **Assess effectiveness of operations modifications on bat fatalities.** Work with other researchers on field studies assessing changes in bat fatalities as a result of shutdown or “feathering” of wind turbine blades and changes to “cut-in” speed. These experiments could be conducted on low-wind nights when power production is relatively low and could include an observational component using thermal infrared imaging as well as a carcass count to determine if the feathering or curtailment reduces fatalities.
- **Evaluate the effectiveness of buffer zones in reducing impacts to birds and bats.** Identify habitat-specific and species-specific buffer zone mitigation strategies that have been employed at operating wind energy projects and assess the effectiveness of these buffers in avoiding direct and indirect impacts. Review and compile information from the scientific literature for species in California that have been considered sensitive and recommended for buffering.

Long-Term Research

In the decades to come, researchers will have a much improved data set and tools with which to analyze long-term trends and patterns of impacts to birds and bats at California’s wind resource areas. Consistent application of the methods recommended in the *California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development* (published by the Energy Commission and the California Department of Fish and Game in October 2007) will eventually produce comparable statewide data that can be used to more accurately estimate impacts to birds and bats from wind energy development, and to successfully avoid or reduce those impacts. With a consistent California data set on wind-wildlife interactions and the results of the research goals described above, the following long-term goals can be addressed:

- **Develop bird and bat fatality estimates for California wind resource areas and identify correlates of risk.** Conduct a meta-analysis of pre-permitting and operations fatality data from wind energy developments that used methods recommended in the *Guidelines*. This relatively consistent data set can be used to develop a range of fatality estimates for birds and bats at wind resource areas throughout California, focusing on wind resource areas that will experience significant expansion and/or repowering. This analysis should include an assessment of how variables measured during pre-permitting studies correlate with monitored bird and bat fatality rates throughout the state.

- **Develop species/habitat maps for California wind resource areas.** Compile data base/maps that would provide the following information for California's wind resource areas: the location, magnitude, and timing of movements of California bats and birds during spring and fall migration; areas occupied by species of special concern during the breeding and non-breeding seasons; and ecologically important/sensitive habitats. The maps should be accessible to wind energy developers, resource agencies, decision makers, and the public, and provided in a form that allows the maps to be overlaid with regional land use and conservation plans.
- **Conduct studies to assess cumulative population impacts.** For species deemed to be at risk of significant population declines due to wind energy development, conduct lab analyses of feathers or carcasses to determine age and geographic origin of individuals killed at wind turbines. Evaluate patterns of mortality, identify most susceptible groups of individuals, and determine whether populations of birds or bats killed are of local origin or not. If warranted, conduct population viability analyses for species in California that may be at risk of cumulative population impacts.
- **Evaluate effectiveness of compensatory mitigation in offsetting impacts to birds and bats.** Identify wind energy projects that have included compensatory mitigation and compile information about the effectiveness of that mitigation in achieving the stated objectives. Evaluate the nexus between the fatalities occurring during operation of the wind turbines and the benefits provided by habitat acquisition and enhancement to impacted species. Recommend better ways to implement compensatory mitigation and more closely link the impact of wind energy development with the mitigation proposed to offset that impact.

Roadmap Organization

This roadmap is designed to help researchers determine research priorities, and evaluators to determine whether a particular proposal meets current research goals. The chapters build upon each other to provide a framework and justification for the proposed research and development:

- Chapter 1, Issue Statement, states the issues to be addressed.
- Chapter 2, Public Interest Vision, provides an overview of research needs in this area and how PIER plans to address those needs.
- Chapter 3, Background, establishes the context of PIER's work addressing avian and bat interactions with wind turbines.
- Chapter 4, Research Needs, identifies specific research needs that are not already being addressed.
- Chapter 5, Goals, outlines proposed PIER activities that will meet those needs.
- Chapter 6, Leveraging R&D Investments, identifies methods and opportunities to help ensure that the investment of research funds will achieve the greatest public benefits.

- Chapter 7, *Areas Not Addressed by This Roadmap*, identifies research pertinent to avian and bat interactions with wind turbines that the proposed activities do not address.

Chapter 8 lists references, while Chapter 9 provides a detailed glossary and list of acronyms.

Appendix A lists the people and organizations that contributed information for this roadmap;

Appendix B specifies the Latin names of animals mentioned in the report.

Chapter 1: Issue Statement

The California Energy Commission and California Department of Fish and Game released *California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development* (*Guidelines*) in October 2007 to provide recommended protocols for assessing and minimizing the impacts of wind energy development to birds and bats. While wind turbine–wildlife interactions have been the subject of study for over twenty years, many uncertainties remain as to the best methods for the biological assessment, mitigation, and monitoring of wind energy projects. This Roadmap identifies research that will help resolve the most significant of those uncertainties that are pertinent to California. The results of this research will improve methods to assess and mitigate impacts of wind energy development on birds and bats in California and will inform future revisions of the *Guidelines*.

Chapter 2: Public Interest Vision

The Public Interest Energy Research (PIER) Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

California's Renewables Portfolio Standard (RPS) requires that the state's electricity providers serve 20 percent of their retail load from renewable resources.¹ The California Energy Commission's *2004 Integrated Energy Policy Report Update* recommends an even more ambitious goal of 33 percent renewable energy by 2020. The largest increase in renewable energy resources to meet the 20 percent RPS will be from wind generation because new wind generating facilities are the fastest renewable resource to install and interconnect to the power grid (California ISO 2007).

In 1995, California produced 30 percent of the world's wind-generated electricity (2.9 billion kilowatt hours), but wind development in the state slowed considerably in the 1990s (Sternier 2002). Uncertainty from electric industry restructuring, loss of federal and state economic incentives, and expired utility contracts played a role in the slowdown, but another important factor was documentation of bird fatalities from collisions with wind turbines, particularly at the Altamont Pass Wind Resource Area in Alameda County, California (Estep 1989; Orloff and Flannery 1992). Since that time, concerns about impacts to birds from turbine collisions have continued to be a source of controversy, and collisions with wind turbines have caused some delays in new wind energy projects in California and other states (Dorin 2005; Sternier 2002; Erickson et al. 2001). More recently, wind turbine collisions with bats have also been identified as a potentially significant source of concern (CBWG 2006).

Delays in permitting new wind energy projects could impede achievement of California's renewable energy standards. Accordingly, the Energy Commission's *2005 Integrated Energy Policy Report* recommended the development of statewide protocols to address avian impacts from wind development. A statewide guidelines effort was further stimulated by a January, 2006, conference in Los Angeles, "Understanding and Resolving Bird and Bat Impacts." At this conference many participants encouraged the Energy Commission and the California Department of Fish and Game (CDFG) to collaborate, with input from all interested parties, in

1. The Renewables Portfolio Standard was originally placed in statute in 2002 with the passage of Senate Bill 1078 (Sher Chapter 516, Statutes of 2002), calling for 20 percent renewable energy by 2017. The Energy Action Plan, adopted by the California Public Utilities Commission and the California Energy Commission, accelerated the Renewables Portfolio Standard target to achieve 20 percent renewable energy by 2010.

developing voluntary statewide guidelines to promote the development of wind energy while minimizing impacts to birds and bats.

The Energy Commission and CDFG began developing voluntary guidelines in May of 2006, and released the final *California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development (Guidelines)* in October of 2007. Development of the *Guidelines* was a collaborative effort involving eight public workshops and more than 80 interested parties, including representatives from wind industry, resource agencies, environmental groups and other non-governmental organizations, utilities, county planning departments and elected officials, universities, and research institutes. In the course of working on the *Guidelines*, a consistent theme expressed by many of these participants was the need for additional research to resolve areas of uncertainty regarding bird and bat interactions with wind turbines (see www.energy.ca.gov/renewables/06-OII-1 for transcripts or summaries of comments at the public workshops and comment letters). Throughout the *Guidelines* effort researchers, wildlife agency personnel, and representatives from wind industry and conservation groups reiterated their concerns about the lack of information on certain aspects of wind turbine-wildlife interactions. In particular, participants expressed a need to establish a better linkage between pre-permitting data on bird and bat use with fatalities during turbine operation, and to provide scientific validation for techniques to avoid, minimize, and mitigate for bird and bat fatalities. In addition, they noted that more research is needed on the cumulative effects of wind energy development on California's bird and bat populations.

The Energy Commission has been a leader in researching bird-wind turbine interactions for decades, starting in the mid-1980s with research by an Energy Commission biologist who compiled a database of bird fatalities at California wind resource areas (WRAs) (Haussler 1988). Since then the Energy Commission and its PIER Program have supported many studies addressing bird-wind turbine interactions (Orloff and Flannery 1992, 1996; Anderson and Estep 1988; Estep 1989; Hunt 2002; Smallwood 2007; Smallwood et al. 2008; Smallwood and Thelander 2004).

In 2006 the RD&D Committee of the Energy Commission authorized funding for science to improve pre-permitting and operations monitoring methods as well as mitigation of impacts. The research program was to follow development and final adoption of the *Guidelines*. To ensure this research addresses the issues of highest priority in California, the Energy Commission's PIER Program has developed this Roadmap to identify research needed to increase certainty in methods and metrics used to assess and mitigate impacts to birds and bats from wind energy facilities.

To assist in preparation of the Roadmap, PIER-Environmental Assessment (EA) staff held a public workshop on November 2, 2006. (A summary of this meeting, "Research Needs to Support Avian/Bat Assessments and Mitigation," is available at <http://www.energy.ca.gov/windguidelines/documents/index.html#meetings>.) PIER-EA staff also contacted researchers, wind industry representatives, resource agency personnel, and other parties with interest and expertise in wind-energy/wildlife research. Appendix A provides a list of individuals contacted before and during Roadmap development.

Chapter 3: Background

This chapter provides background information about research on bird and bat interactions with wind turbines and describes relevant findings from studies and monitoring reports for proposed and operating wind energy projects.

Pre-Permitting Studies

Some of the most important information needed to assess collision risk is data on the abundance and behavior of birds and bats in the vicinity of the proposed wind turbines. For diurnally active birds, techniques such as bird use counts or point counts are typically used to estimate the relative abundance of birds in the project area and to evaluate their behavior relative to the risk of collision with wind turbines. Also, site-specific factors that may influence risk assessment during pre-permitting studies are the topography of the project site, tower design and micro-siting (i.e., placement of turbines within a wind resource area), location of the site relative to migratory pathways, and environmental and habitat features such as feeding or nesting suitability that might affect site use. For bats and nocturnal birds, the methods and technologies are more complex and the results less certain compared to diurnal bird survey techniques. The following discussion describes what is known about the risk of bird and bat collisions as a function of bird/bat occurrence and wind facility features, and how these factors are assessed with pre-permitting studies.

Bird Interactions with Wind Turbines

Diurnal Bird Occurrence and Risk

Assessing risk (defined here as the risk of a bird colliding with a wind turbine) requires an estimate of the number of individuals exposed to collisions and some quantification of behaviors that might put birds at risk. The number of diurnal birds present at a site can be determined using point counts—i.e., a human observer simply counting all individual birds present within a certain radius of a specific observation point (Ralph et al. 1995). Point counts can also be used to estimate species richness and species diversity (Smallwood and Thelander 2005; Kerlinger 2002). Visual scans, or use counts (referring to a bird's "use" of local airspace), are similar to point counts and are now widely used for pre-permitting studies of diurnal birds at proposed wind energy project sites (Anderson et al. 2005; Erickson et al. 2003b; Howell and Noone 1992; Orloff and Flannery 1992; Rugge 2001; Smallwood and Thelander 2004, 2005). Use counts are a modification of the standard point count and involve an experienced observer recording bird detections from a single vantage point for a specified period of time, typically 20–30 minutes. Unlike most point counts, use counts also include observations of bird behaviors such as flight height, which can correspond to the heights of rotor planes of the proposed wind turbines. Use counts help offer information useful for micro-siting of turbines because extended observations reveal project features that might attract birds to the risk zone.

During bird use surveys, researchers typically record the height of the bird above ground relative to the future rotor height. Operations monitoring reports occasionally analyze the relationship between the pre-permitting observations of birds flying within the rotor risk zone

to the actual number of fatalities (e.g., Kerlinger et al. 2006). However, more research is needed to determine how accurately the metric of flight height estimates risk, and to assess how this varies among species.

While the methods for assessing numbers and behavior of diurnal birds are relatively standardized, uncertainties remain in determining the appropriate sample size needed to reliably estimate relative abundance and how to assess risk based on data about the abundance and flight paths of birds at proposed wind energy facilities. Furthermore, little systematic research has been done on how varying the radius of the visual scan or the duration of the surveys might affect the calculation of relative abundance at project sites, and how this abundance estimate relates to fatalities during operations.

Another area of uncertainty is the usefulness of bird utilization and fatality data from existing wind energy facilities in estimating impacts of proposed, adjacent wind energy projects, or those that are similar in terms of turbine type. A number of recent proposed wind energy projects in California have used data from adjacent sites or from wind resource areas in other parts of the country to estimate fatalities during operation (Kerlinger et al. 2006; Young et al. 2007). Comparing these pre-permitting estimates of fatalities to actual operations fatality data will provide information as to the validity of this method in estimating fatalities.

As discussed in Chapters 4 and 5, some of these uncertainties may be resolved by a reanalysis of data from existing wind energy facilities and/or by collecting new data at proposed facilities.

Behavioral Avoidance and Bird Species Variation in Risk

An estimate of the relative abundance of bird species at a proposed site is only part of the risk assessment equation. Abundance and behavior interact to influence the exposure of birds to collisions with wind turbines. Many of the reported fatalities at California wind resource areas are among resident species, particularly raptors, so the flight avoidance behavior of resident birds is of particular interest in predicting collision risk.

Studies of birds approaching wind turbines indicate that most birds change their flight behavior to avoid them (Strickland et al. 2001). Birds may alter flight direction, height, or speed or engage in evasive maneuvers to avoid contact with a turbine. Winkelman (1995) observed that during more than 1,100 observations, 75 percent of the reactions occurred 100 m from the turbines. At closer distances birds showed specific avoidance behaviors, including accelerated wing beats, fluttering flights, and alteration of the angle of their bodies.

Species-specific differences in body and wing morphology and visual acuity are likely to influence maneuverability and avoidance capabilities. Those species with reduced maneuverability may have a greater likelihood of collision when response time is limited (Winkelman 1995; Kingsley and Whittam 2005). For example, species like northern goshawks that hunt in forests are more adapted to flying through complex environments (trees and limbs) than species that hunt in open country (Kerlinger 1995). Such species may therefore be less subject to collision than open-country species (for example, northern harriers) because of their greater flight maneuverability when encountering stationary objects while flying.

Because of these variations in behavior, morphology, and other factors, bird species vary in their susceptibility to collisions, a vulnerability that has been well documented for raptors in California. Some of the earliest studies on fatalities at wind farms noted that species were disproportionally killed in relation to their abundance. Orloff and Flannery (1992) observed at the Altamont Pass Wind Resource Area in Alameda County, California, that the common raven and turkey vulture were two non-raptor species frequently observed at the site, but at little risk with few fatalities. Other researchers have reported corvids as a common group of birds flying near the rotor-swept area of turbines, yet corvids are rarely found during carcass searches (Erickson et al. 2004; Smallwood and Thelander 2004).

Recent studies at the High Winds project site in Solano County (Kerlinger et al. 2006) found similar results for other species: the avian species with the largest number of recorded fatalities (45) was the American kestrel, which was observed only 496 times during their use counts. The most abundant birds were red-winged blackbirds, observed 4,248 times, but researchers recorded only 14 fatalities of this species (Kerlinger et al. 2006). Other species that have consistently higher fatality rates than predicted based on relative abundance are red-tailed hawks and golden eagles (Orloff and Flannery 1992; Smallwood and Thelander 2004, 2005).

The most common fatalities reported in western and midwestern wind energy facilities are resident passerines such as horned larks, which perform aerial courtship displays that put them into the rotor-swept area of the turbines (National Research Council 2007). The western meadowlark is a common resident passerine often recorded as a fatality at wind energy facilities, even though it is rarely seen flying at the altitude of the rotors (Arnett et al. 2007).

More research is needed to characterize behavioral avoidance of bird species/species groups at California wind resource areas at a representative array of turbines and habitats, and to assess which pre-permitting data collection techniques best capture the behaviors that put species at collision risk. General information about species differences in fatality rates at wind resource areas are currently used to make qualitative assessments of potential risk, but, ideally, quantitative data should provide the basis for pre-permitting assessments of collision risk.

For some species groups, like raptors, sufficient data are already available to quantify risk based on pre-permitting use data. Table 1, modified from Appendix G from the *Guidelines* (CEC and CDFG 2007), presents data from studies at wind energy projects in California, Oregon, Washington, Wyoming, and Minnesota. With the exception of Tehachapi and San Geronio, the wind turbines at these sites are the newer-generation models (0.6 MW to 1.5 MW) or similar.

The kinds of data in Table 1 can be used to generate explicit estimates of operations fatalities based on pre-permitting data. For example, at the proposed Hatchet Ridge project in Shasta County, California, Young et al. (2007) used the significant correlation ($r^2 = 90.3\%$) between raptor use and raptor collision mortality from sites across the country that had similar turbines. They estimated the raptor collision fatality rates would be 0.06/MW/year, or six raptors per year for a 100-MW project (Young et al. 2007). Follow-up studies analyzing the accuracy of these estimates would provide useful information about the validity of this approach.

Table 1: Raptor Use and Raptor Fatalities at Wind Resource Areas (modified from Energy Commission and CDFG 2007)

Study Site	Raptor Use/30-Minute Count *	Raptor Fatalities/MW Installed	Source
High Winds, CA	5.250	0.68	Kerlinger et al. 2006
Shiloh I, CA**	--	0.80	Kerlinger et al. 2008
Diablo Winds, CA**	4.350	0.52	WEST 2006
Combine Hills, OR	1.350	0.00	WEST 2006
Tehachapi Pass, CA**	0.900	—	Anderson et al. 2004
Foote Creek Rim, WY	0.735	0.04	Young et al. 2003
Buffalo Ridge, MN	0.720	0.02	Johnson et al. 2000
Klondike, OR	0.705	0.00	Johnson et al. 2003
Nine Canyon, WA	0.660	0.05	Ericson et al. 2003
Stateline, WA/OR	0.615	0.09	Erickson et al. 2003a, 2004
Vansycle, OR	0.450	0.00	Erickson et al. 2000
San Geronio, CA	0.150	0.03	Anderson et al. 2005

*For several of these studies, raptor use had been estimated using 20-minute counts, so the data in this table were adjusted to provide a uniform metric of raptor use per 30-minute count.

**A range of 0.40 to 0.64 raptor fatalities per MW per year was calculated for Diablo Winds—the mid-range value of 0.52 is used in this table. Fatality data for studies at Tehachapi, California, were not included because carcass searches were too infrequent to be comparable to other studies.

Collision Risk Models

Tucker (1996), Podolsky (2005), and Band et al. (2007) have attempted to develop models of collision risk based on turbine characteristics and bird use. Calculating collision risk under the Band model is a two-stage process, with the number of birds colliding per year equal to the number flying through the rotor (Stage 1) x probability of a bird flying through the rotor being hit (Stage 2). Pre-permitting data collection on bird use provides the Stage 1 information about bird use of the site and the frequency of bird flights in the area swept by the turbine blades. For Stage 2, the probability of collision depends on the size of the bird (both length and wingspan), the breadth and pitch of the turbine blades, the rotation speed of the turbine, and the flight speed of the bird.

All three models (Tucker, Podolsky, Band) make the unrealistic assumption that birds take no action to avoid collision. Because none of the models incorporate behavior (e.g., avoidance or attraction), a critical factor in risk assessment, they currently have little value in estimating actual fatality rates (Chamberlain et al. 2006). As with all models, theoretical estimates must be compared to empirical data on bird and bat use and fatality rates. Development of collision risk models continues to be of interest worldwide and to organizations such as the National Wind Coordinating Collaborative. To make collision risk models a useful tool for California risk

assessments, more research is needed on wind turbine avoidance behavior for California bird species potentially at risk.

Nocturnal Bird Occurrence and Risk

Determining the number of nocturnal birds and bats present at a proposed site and estimating their exposure to risk of collision is a more difficult task than for diurnal birds. Answering the most basic questions about numbers and use requires a variety of methods and techniques that, unlike diurnal bird study methods, have not been consistently applied and tested. Observing nocturnally active birds and estimating where, when, how, and why they come into contact with wind turbines requires techniques such as acoustic detection, night vision observations, reflectance and thermal infrared imaging, marine radar, and Doppler weather surveillance radar (NEXRAD). Kunz et al. (2007) and the National Research Council (2007) provide comprehensive descriptions of these techniques and their strengths and limitations.

Fatalities of nocturnal migrant songbirds have been reported at wind energy facilities throughout the United States, particularly on forested ridgetops in the eastern United States, such as Buffalo Mountain Wind Energy Center in Tennessee and Mountaineer Wind Energy in West Virginia (Kerns and Kerlinger 2004; GAO 2005; Arnett et al. 2008). Erickson et al. (2001) reviewed bird collision data from 31 studies at wind energy facilities in the United States and found that approximately half of the fatalities were nocturnal migrating passerines. The number of passerine fatalities reported from these studies range from no birds during a five-month survey at the Searsburg Vermont Wind Energy Facility, (Kerlinger 2002) to 11.7 birds per megawatt (MW) per year during a one-year study at Buffalo Mountain Wind Energy Center (Nicholson 2003).

Most songbirds, waterfowl, shorebirds, herons, and egrets migrate at night (Kerlinger and Moore 1989), and radar studies yield some insight into general patterns of night flying behavior. Nocturnal migrants generally take off after sunset, ascend to their cruising altitude between 300 and 2,000 feet (90 to 610 meters), and return to land before sunrise (Kerlinger 1995). For most of their flight, songbirds and other nocturnal migrants are above the reach of wind turbines, but they pass through the altitudinal range of wind turbines during ascents and descents and may also fly closer to the ground during inclement weather or when negotiating mountain passes (Able 1970; Richardson 2000).

In general, studies show that the paths of high-elevation nocturnal migrants are little affected by topography or habitat beneath, but some studies suggest that landforms can have a significant guiding effect for birds flying below 3,300 feet (1,000 meters) (Williams et al. 2001). Most migrating birds fly well above the elevation of even the tallest turbines, but may also fly higher in response to turbines to avoid them. In Tarifa, Spain, observations of 72,000 migrating birds showed that birds flew at higher average altitudes (>100 m versus 60 m) over wind turbines than over two other reference areas without wind turbines (Janss 2000). More information is needed as to the behavioral responses of nocturnal migrants when flying above wind resource areas, and whether this response is specific to species or species groups (for example, nocturnal migrating songbirds versus waterfowl).

Radar studies reveal that major nocturnal migrations are triggered by weather (Gauthreaux and Belser 2003) and often occur on nights with light tailwinds. Inclement weather has been noted as a contributing factor in avian collisions with power lines, buildings, and communications towers (Estep 1989; Manville 2001), and Johnson et al. (2002) estimated that as many as 51 of 55 collision fatalities at the Buffalo Ridge facility may have occurred in association with thunderstorms, fog, and gusty winds. Low cloud cover or headwinds can reduce the altitudes of migrants, bringing more birds within range of turbine blades (Richardson 2000).

Radar-based studies have occasionally been used in California as a pre-permitting survey method, particularly when preliminary studies indicate potential risk to bats or nocturnally active birds. The first such study conducted in the state was McCrary's work at the San Geronimo Wind Resource Area (McCrary 1984a, 1984b). More recently radar studies have been conducted at proposed wind energy facilities in Shasta and Humboldt counties (Mabee and Sanzenberger 2008; Sanzenberger et al. 2007; McAllister and Fix 2008) and in Kern County (LeMay pers. comm.). The approach used in these studies is to collect baseline information on the flight direction, migration passage rates, and flight altitudes of nocturnally migrating birds and bats, and then estimate the number of targets that would pass within the rotor-swept area of the proposed wind turbines during the migratory season. Using a number of simplifying assumptions, these studies can generate a quantitative estimate of fatalities (e.g., number of migrants/turbine/day). Follow-up studies are needed to verify the accuracy of these estimates, and to fine-tune the assumptions that lead to the estimate.

No studies in California have yet combined fatality monitoring at existing wind resource areas with radar, although this research has been conducted at Stateline Wind Resource Area in Oregon/Washington, Buffalo Ridge in Minnesota, and Nine Canyon, Washington (Young and Erickson 2006). Results suggest that the proportion of migrants killed by wind turbines is small compared to the number of birds flying overhead. More research is needed to examine the height at which birds migrate and their potential vulnerability to collision with the new-generation taller turbines, to assess how topographic and habitat variables at a site might affect collision risk, and to assess the value of radar in estimating fatalities of nocturnal migrants.

A coalition of scientists and resource managers from the United States Geological Survey (USGS), United States Fish Wildlife Service (USFWS) and other research institutes recently identified the need to work together more closely to foster radar-related research and software development (Ruth et al. 2005). Richard Sojda (USGS), Reginald Mead (Montana State University) and their colleagues are currently exploring techniques to use NEXRAD weather radar data to map bird migration corridors, particularly for waterfowl, with the goal of mapping bird migration pathways in the Upper Midwest and then the rest of the country. (Sinclair pers. comm.). These researchers were awarded a subcontract with the Department of Energy/National Renewable Energy Laboratory to conduct this proposed work (Sinclair pers. comm.).

Coordinated nationwide efforts are now under way to conduct more radar-based studies to understand the movements of songbirds, waterfowl, and bats, with the goal of providing the knowledge and tools needed to assist in the siting of wind energy projects and other facilities,

as well as enhancing migratory bird habitat projects. This collaboration addresses the growing consensus among land managers and conservation organizations (including USFWS, Partners in Flight, North American Bird Conservation Initiative, The Nature Conservancy, Bat Conservation International) that studies of migratory species must focus attention at a larger, landscape-level approach rather than site by site. California researchers would also benefit from a collaborative approach to assessing the utility of radar-based studies as a way to estimate nocturnal migrant fatalities.

Role of Lighting and Nocturnal Migrant Bird Collisions

Lights can attract nocturnal migrant songbirds, and major bird kill events have been reported at lighted communications towers (Manville 2001). Lighting on communications towers is known to attract migrating birds and increase their risk of collision with towers (Kerlinger 2004), but most kills are from towers higher than 300 to 500 feet. Many of the avian fatalities at communications towers and other tall structures have been associated with the steady-burning red lights typically recommended by the Federal Aviation Administration (FAA). However, with one exception, there is little evidence that lighting at wind turbines causes high numbers of nocturnal passerine bird fatalities as it does at communication towers (Erickson et al. 2001). The exception is from the Mountaineer Wind Energy Center in West Virginia, which reported 27 passerine fatalities on a foggy night on May 23, 2003 (Kerlinger and Kerns 2003). These researchers concluded that this large bird kill was due to the bright sodium vapor lights at a substation adjacent to the wind turbines, combined with foggy conditions. Kerlinger and Kerns analyzed data from other monitoring studies (Johnson et al. 2002; Fiedler 2007; Kerlinger 2002; Erickson et al. 2000; Erickson et al. 2003; Johnson 2000) and found no significant relationship between lighting and fatalities of nocturnal migrants. Recent studies at the Collinsville Montezuma Hills Wind Resource Area in Solano County, California, also support the conclusion that the red flashing FAA obstruction beacons used on wind turbines do not increase bird fatalities (Kerlinger et al. 2007).

Lighted wind turbines are less likely to produce the kind of high avian fatality rates observed at communication towers because communication towers (1) are much taller than wind turbines, reaching into the airspace occupied by nocturnal bird migrants; (2) are typically supported by guy wires, which are associated with higher rates of bird collisions; and (3) use different lighting than wind turbines. Steady-burning, red incandescent L-810 lights used at communications towers seem to attract birds (Gehring et al. 2006). Lighting at wind turbines tends to be red strobe or red-blinking/pulsating incandescent lighting. Longcore et al. (2008) concluded that use of strobe or flashing lights on towers resulted in less bird aggregation, and, by extension, lower bird mortality, than use of steady-burning lights.

Considerable research has been conducted on the effect of lighting as it relates to hazards to nocturnal bird migrants at communication towers (see Longcore et al. (2008) for a meta-analysis on this subject). No further research is proposed on lighting and bird collision risk in this Roadmap because it is a topic that has been well studied in other forums, and because clear-cut management recommendations on lighting for wind turbines have already been formulated based on that research.

Bat Interactions with Wind Turbines

Avian collisions with wind turbines have been studied for almost two decades, but only recently have researchers begun to focus on bat fatalities at wind energy facilities. As with nocturnal birds, our understanding of how bats interact with wind turbines is limited by the difficulty of observing how they behave near these structures. Some of the highest bat fatality rates have been recorded at wind energy facilities built along forested ridgetops in the eastern United States (GAO 2005; Kunz et al. 2007; National Research Council [NRC] 2007), with bat fatality rates as high as 53.3 bats/MW/year (Kunz et al. 2007; Fiedler et al. 2007). Table 2 summarizes estimates of bat fatalities from wind energy projects throughout North America.

Until recently few studies had been conducted at California wind energy facilities to specifically address bat fatalities, although some had been detected incidentally in the course of searches for bird carcasses. Howell and DiDonato (1991) reported finding one red bat carcass during a 12-month period, and Orloff and Flannery (1992) reported two dead bats over a 24-month period. Fatality monitoring at the Altamont Pass Wind Resource Area detected seven bat carcasses (hoary, western red, and Mexican free-tailed bats) during avian monitoring from October 2005 to October 2007 with searches occurring approximately every 40 days (Altamont Pass Avian Monitoring Team 2008a).

The High Winds and Shiloh I projects in Solano County are among the few studies in California where searches have been specifically conducted for dead bats beneath the turbines (Kerlinger et al. 2006, 2007). At High Winds, carcass surveys were conducted approximately two times per month; searchers found remains of 116 dead bats between 2003 and 2004 (Kerlinger et al. 2006). Kerlinger et al. (2006) estimated an adjusted total² of 619 bats killed at High Winds turbines over the two-year study, or an average of 2.02 bats/MW/year. Hoary bats were the most common species fatality, followed closely by Mexican free-tailed bats. Smaller numbers of western red and silver-haired bats were also found.

At the Shiloh I site, carcasses were counted weekly. Bat fatality rates were estimated at 5.24 bats/MW/year for the first year and 3.83 bats/MW/year for the second year of study. The same bat species were recorded as fatalities at Shiloh I as at High Winds.

2. As will be discussed later in this chapter, actual carcass counts are adjusted to account for scavenging, searcher efficiency error, and other variables.

**Table 2: Estimates of Bat Fatalities at Wind Facilities in North America
(modified from Arnett et al. 2007)**

Study Area	Estimated Fatality/Turbine/Year	Estimated Fatality/MW/Year	Source
Canada			
Castle River, Alberta	0.5	0.8	Brown and Hamilton 2002
McBride Lake, AB	0.5	0.7	Brown and Hamilton 2002
Summerview, AB	18.5	10.6	Brown and Hamilton 2006
Eastern U.S.			
Buffalo Mt, TN (Phase 1)	20.8	31.5	Nicholson 2003, Fiedler 2004
Buffalo Mt, TN (Phase 2)	35.2	53.3	Fiedler et al. 2007
Buffalo Mt, TN	69.6	38.7	Fiedler et al. 2007
Maple Ridge, NY	24.5	14.9	Jain et al. 2007
Meyersdale, PA	23	15.3	Arnett 2005
Mountaineer, WV (2003)	48	32	Kerns and Kerlinger 2004
Mountaineer, WV (2004)	38	25.3	Arnett 2005
Rocky Mountains US			
Judith Gap, MT	13.4	8.9	TRC 2008
Foote Ck Rim, WY	1.3	2.0	Young et al. 2003
Western U.S.			
High Winds, CA	3.4	1.9	Kerlinger et al. 2006
Shiloh I, CA (2006)	7.9	2.5	Kerlinger et al. 2008
Shiloh I, CA (2007)	5.7	3.83	Kerlinger et al. 2008*
Klondike, OR	1.2	0.8	Johnson et al. 2003a
Stateline, OR/WA	1.1	1.7	Erickson et al. 2003b, 2004
Vansycle, OR	0.7	1.1	Erickson et al. 2001
Nine Canyon, WA	3.2	2.5	Erickson et al. 2003a
Midwestern U.S.			
Buffalo Ridge, MN (Phase 1)	0.1	0.3	Johnson et al. 2003a
Buffalo Ridge, MN (Phase 2)	2.0	2.7	Johnson et al. 2003a, 2004
Buffalo Ridge, MN (Phase 3)	2.1	2.7	Johnson et al. 2004
Lincoln, WI	4.3	6.5	Howe et al. 2002
North Iowa	7.8	8.7	Jain 2005
South-central U.S.			
Woodward, OK	1.2	0.8	Piorkowski 2006

Bat Species Vulnerable to Collisions

Eleven of the 45 species of North American bats have been among fatalities reported at wind facilities (Johnson 2005). Nationwide, migratory foliage-roosting species, such as hoary bats, eastern red bats, and silver-haired bats, account for the greatest numbers of assessed mortalities (83.2 percent) (Johnson 2005; Kunz et al. 2007; Arnett et al. 2007). In Europe, migratory species also dominate fatalities (Durr and Bach 2004). Eastern pipistrelles account for as much as 25.4 percent of total bat fatalities at wind facilities in the eastern United States (Kerns et al. 2005). The only two investigations at wind facilities within the range of the Mexican free-tailed bat, a cave-roosting species, report high proportions of fatalities of that species: 31.4 percent in California (Kerlinger et al. 2006) and 85.6 percent in Oklahoma (Piorkowski 2006).

Based on the limited data on bat fatalities at California's wind energy facilities, it appears that the greatest risk is to migratory species. Table 3 lists the California bat species known or thought to be migratory and therefore potentially at risk from collision with wind turbines that occur along their migratory routes.

Table 3: Bat Species Potentially at Risk of Collision with Wind Turbines in California (modified from CBWG 2006)

Name	Status*	Recorded as fatality at California WRAs	Migratory status in California
Silver-haired bat	WBWG:M	Occasional fatality	North-south migrant
Western red bat	DFG:SSC WBWG:H	Occasional fatality	North-south migrant;
Hoary bat	WBWG:M	Most frequently recorded bat fatality	North-south migrant
Mexican free-tailed bat		Frequently recorded as fatality	North-south migrant
Mastiff bat	DFG:SSC WBWG:H	No records of fatalities	Likely migratory, but little information available on migratory patterns
Pocketed free-tailed bat	DFG:SSC WBWG:M	No records of fatalities	Likely migratory, but little information available on migratory patterns
Big free-tailed bat	DFG:SSC WBWG:MH	No records of fatalities	Likely migratory, but little information available on migratory patterns

* **Status Codes:**

DFG:SSC = Department of Fish and Game: California Species of Special Concern

WBWG = Western Bat Working Group

H = High priority. Bat species considered the highest priority for funding, planning, and conservation actions. These species are imperiled or are at high risk of imperilment

M = Medium priority. This designation indicates a level of concern that warrants closer evaluation, more research, and conservation actions of both the species and possible threats.

It should not be presumed that impacts do not occur to these and other species outside the migratory season, and under other circumstances, such as during routine foraging (Kerns et al.

2005). Many of California's 25 bat species do not occur in the areas where wind turbine impacts have been reviewed. For example, all the molossid species like Mexican free-tailed bats are aerial flock foragers and active year round, and thus potentially at risk throughout the year (CBWG 2006).

In general, bat migratory movements within California are diverse, complex, and poorly understood. While north-south bat migration has been at least locally documented for several species, flyways are poorly known, and trans-Sierra, elevational, and interior-to-coast migrations apparently also occur (Rainey pers. comm.). California's large latitudinal range provides both migratory pathways and migratory destinations, with some species likely raising young in northern and central California. The complex distribution and seasonal movements of California bat populations make prediction of turbine impacts all the more challenging.

Seasonal and Spatial Distribution of Bat Fatalities at Wind Energy Facilities

Bat fatalities due to wind turbine collisions appear to be highest during fall migration (Arnett et al. 2007). At the High Winds project area in Solano County, most of the bat fatalities were detected during the fall migration, with 78 percent found between August and October 2003, and 80 percent between August and October 2004. Shiloh I and II in Solano County found similar patterns, with more than half of the bat fatalities occurring between August and October (Kerlinger et al. 2008). In his analysis of bat fatalities at wind resource areas throughout the United States, Johnson (2005) reported that approximately 90 percent of 1,628 documented bat fatalities occurred from mid-July through the end of August. Jain et al. (2007) found similar results at the Maple Ridge wind power site in Lewis County, New York, with 228 bat carcasses (69.9 percent) found between July 1 and August 31, 2006.

Bat collision fatality seems relatively lower during spring migration compared to fall migration. Migratory tree bats may follow different migration routes in the spring and fall (Cryan 2003), and behavioral differences between migrating bats in the spring and fall also may be related to mortality patterns (Johnson 2005). Additional studies on bat fatalities are needed during spring migration to assess correlates of bat fatalities and to determine if the species composition of fatalities differs between fall and spring migration. Weller (2008) is conducting acoustic monitoring studies at a wind resource area near Palm Springs, California, and collecting data to better understand seasonal patterns of bat activity.

Kerns et al. (2005) conducted daily fatality searches at the Mountaineer and Meyersdale Wind Energy Centers in West Virginia and Pennsylvania, respectively, and found that the timing of bat fatalities over a six-week period at the two sites was highly correlated ($r = 0.8$). Although Kerns et al. (2005) found more male than female fatalities, the timing of the fatality by sex was similar at both sites, as well. Additionally, timing of fatalities of hoary and eastern red bats was similar at the Meyersdale and Mountaineer sites.

Based on the limited studies that have been conducted, no pattern of collisions has emerged with respect to the spatial configuration of turbines (Arnett et al. 2007). Bats apparently do not appear to strike the turbine mast, non-moving blades, or meteorological towers (Arnett 2005). Baerwald et al. (2008) describe evidence that barotrauma (damage to tissue caused by rapid or

excessive pressure change) is the cause of death in a high proportion of bat fatalities at wind energy facilities, and noted that direct contact with turbine blades accounted for only about half of the fatalities. Horn et al. (2008) observed bats through thermal imaging cameras attempting to and actually landing on stationary blades and investigating turbine masts. Cryan (2008) provides explanations as to why bats might be attracted to wind turbines. Arnett et al. (2008) summed up the bat fatality patterns that seem to be emerging from research and monitoring studies as follows:

- Bat fatalities are heavily skewed toward migratory bats and were dominated by lasiurine species in most studies.
- North American studies consistently report peak turbine collision fatalities in midsummer through fall.
- Fatalities are not concentrated at individual turbines (i.e., fatalities are distributed among turbines at facilities), and current studies have not identified consistent relationships with habitat variables (for example, distance to water).
- Red strobe lights recommended by the FAA do not influence bat fatality.
- Bat fatalities are highest during periods of low wind speed.

Research is needed to assess the applicability and consistency of these patterns at California wind energy facilities, and more information is needed on the most useful pre-permitting survey methods for estimating bat fatalities. In California, the U.S. Forest Service in collaboration with the Bats and Wind Energy Cooperative and PPM Energy, Inc. (now Iberdrola Renewables, Inc.) are collaborating on a study funded by the Energy Commission (Weller 2008). This study began in late 2007 at the Dillon Wind site in the San Geronio Pass Wind Resource Area in north Palm Springs, California. The goal is to evaluate the use of automated echolocation detectors as a tool for assessing patterns of bat activity. Echolocation detectors were attached at 2, 22, and 52 meters above ground on meteorological towers to measure bat activity from October 25 to December 5, 2007, and echolocation and meteorological data will continue to be collected until late fall of 2008. Echolocation monitoring will be linked to fatality monitoring at the site beginning in spring 2008. Preliminary findings from Weller's study indicate that using only four out of the twelve meteorological towers (distributed over an area of approximately two square miles) produced precise estimates of mean bat activity at each of the three heights of the detectors, indicating that additional towers would not have appreciably improved estimates during the sampling period. Weller (2008) also found that low wind speeds and higher temperatures were positively correlated with bat activity on a nightly basis.

The Bats and Wind Energy Cooperative has recently undertaken similar multi-year pre- and post-construction studies at the Casselman Wind Project in Pennsylvania and the Hoosac Wind Project in Massachusetts (Arnett et al. 2007) and the Butler Ridge Wind Energy Project in south-central Wisconsin (Redell et al. 2006). Most of these studies began around 2005 and will evaluate whether indices of bat activity gathered before construction using acoustic detectors can predict post-construction fatality of bats at wind energy facilities. The first phase of these

projects involves collecting echolocation calls to develop indices of bat activity; phase two will occur after construction and involve extensive fatality searches for at least two years.

Effect of New Turbine Technology on Risk for Birds and Bats

Because primary wind resource areas in the state are largely developed, most wind energy expansion in California will occur as repowering with more efficient turbines or as new development in secondary wind resource areas (Dorin 2005). Repowering consists of removing older, smaller turbines and replacing them with larger, more efficient turbines. Nearly all new and repowered capacity comes from three-bladed, upwind, horizontal-axis turbines (Kahlon et al. 2006).

Smaller turbines, such as the Kenetech 100 kW, still dominate California wind resource areas. In 2003, nearly 83 percent of the total number of California turbines was less than 200 kW (Kahlon et al. 2006). Larger, more advanced turbines are slowly replacing some of the smaller machines, although in California repowering efforts have slowed recently (Wagman 2008). The 100 kW turbines still dominate wind resource areas that were developed in the late 1980s and early 1990s and are still operating. According to the California Wind Energy Association (2007) many existing California wind energy projects have little economic incentive to repower; transaction costs of a new contract are high because repowering contracts are not standardized and the permitting process can be costly and time-consuming. However, the percentage of turbines in California that are less than 100 kW has gradually been declining and turbines greater than or equal to 500 kW gained by 38 percent over 2002 numbers (Kahlon et al. 2006). Most of the state's newer turbines are rated at least 1 MW in capacity, with some projects using 1.5- and 1.8-MW turbines.

As the turbines' capacity increases, so does their size. Turbines now can be 340 feet (103.6 meters) tall with the blade lengths of 130 feet (39.6 meters). New turbines also typically have a longer operating time and lower rotational rates (~15–27 rpm), operate at lower and higher wind speeds, and may have increased blade tip speed (~80 meters/sec), all of which may affect birds and bats differently than the older turbines.

Arnett et al. (2007) analyzed avian fatality rates for 14 sites outside California where new-generation wind turbines were installed and standardized fatality monitoring was conducted. Estimates of total passerine fatality varied considerably among studies conducted at these 14 facilities, but fatalities per turbine and per MW were similar for all regions represented by these studies. Combined mean fatality rates for these 14 projects were calculated at 0.04 raptors per MW; for passerines, the combined mean fatality rate ranged from zero at the Searsburg Vermont facility (Kerlinger 1997) to 11.7 birds/MW at Buffalo Mountain, Tennessee (Nicholson 2003). Most studies reported that passerine fatalities occur throughout the facility, with no particular relationship to site characteristics. From these 14 studies, which were conducted in states throughout the country but did not include California, approximately half the reported fatalities at new-generation wind facilities throughout North America are nocturnally migrating birds, primarily passerines, and the other half are resident birds in the area.

Barclay et al. (2007) took a meta-analysis approach to assess the influence of turbine size on bird and bat fatalities. These researchers found that the diameter of the turbine rotor did not influence bird or bat fatality. The height of towers had no effect on bird fatalities per turbine, but bat fatalities increased exponentially with turbine height. These results suggest that migrating bats fly at lower altitudes than migrating passerine birds, and that newer, taller turbines are reaching that bat migration airspace. Alternatively, bats may be disproportionately attracted to the taller turbines compared to shorter structures. Replacing older, smaller turbines with fewer larger ones may reduce bird fatalities per megawatt, but such repowering may increase bat fatalities.

Bird use and behavior data collected at Buffalo Ridge, Minnesota, suggest that taller turbines might pose less risk to some groups of birds than smaller turbines because more birds observed during the diurnal surveys flew below the rotor-swept height (Johnson et al. 2000). However, turbine fatality rates at the taller turbines, which also had larger rotor-swept areas, were three times as high as for the shorter turbines. The majority of fatalities were during inclement weather during spring migration (Johnson et al. 2002).

Many avian collision studies in California have been conducted in areas with older, smaller turbines. Studies by Orloff and Flannery (1996) at the Altamont Pass Wind Resource Area found no relationship between avian mortality and turbine height, but subsequent analyses of published studies and monitoring reports found that shorter turbines have a higher rate of golden eagle collisions (Hunt 2002). These studies looked at differences in risk between turbine types based mostly on rotor-swept height, not rotor-swept area, which may also influence risk (Howell 1997).

In more recent studies at the Altamont Pass WRA, researchers found bird use was highest in the same air space occupied by the smaller turbines and concluded that when repowering occurs, fatality rates might decrease (Smallwood and Thelander 2004). Western EcoSystems Technology, Inc. (WEST) (2006) reported on the first year of fatality monitoring in the Diablo Winds Energy Project, which replaced 169 vertical-axis turbines with 31 larger horizontal-axis turbines in the APWRA. The preliminary estimates of bird fatality at the Diablo Winds Project suggest a lower fatality rate for most species compared to the smaller turbines at the APWRA. An analysis by Smallwood (2006) of the Diablo Winds data collected by WEST found that overall bird mortality was reduced by 70 percent and raptor mortality by 62 percent, but fatalities of red-tailed hawks increased three-fold. However, both this interim monitoring report by WEST (2006) and the analysis by Smallwood (2006) caution against drawing firm conclusions from these preliminary data regarding the collision risk of newer turbines versus older turbines. These data are only the first from a multi-year study, and variation in raptor mortality from year to year can be very high. Furthermore, the authors point out that the protocol by which the data were collected and analyzed varied considerably between the Diablo Winds monitoring study and comparison data in Smallwood and Thelander (2004). Smallwood (2006) also notes that mortality adjustments in the first year of monitoring included multiple uncertainties and potential statistical biases, and that the sample size of fatalities was small. Several years of monitoring at Diablo Winds will be needed to make more robust comparisons of mortality

before and after the project, and to make conclusions about the effect of repowering on bird fatalities.

Repowering projects currently underway in the Collinsville Montezuma Hills Wind Resource Area (Shiloh I and II and High Winds projects, Solano County) provide additional opportunities to compare bird and bat fatality rates associated with new turbine technology. Many of the new turbines will be installed immediately adjacent to old turbines, and many of these older turbines are the same as those in the Altamont Pass Wind Resource Area, for which there is a large data set. Until some of the monitoring studies are complete for these repowering projects, it is unclear whether larger and smaller wind turbines cause equivalent bird collision fatalities based on rotor-swept area or MW of generating capacity. The effects of taller turbines on bats and nocturnal migrants have not yet been investigated with the same level of effort that has been expended on some species of raptors and other diurnal birds. Given the lack of sufficient information about turbine size effects and the data suggesting that taller turbines can increase the risk to bats (Barclay et al. 2007), it cannot be assumed that placement of large turbines will reduce or increase avian or bat collision risk for all species because differences in fatality rates attributable to turbine heights and rotor-swept areas vary among study sites and among species and groups of species.

Estimates of impacts of future wind energy development are based on data from old and new turbines, and it is important to understand how changing technology affects fatality estimates for different taxa of birds and bats. Chapter 4 describes the research questions that need resolution to improve our ability to assess the risk of newer, larger turbines on raptors, migratory birds, and bats.

Effects of Turbine Siting, Perch Availability, and Topography on Risk

Orloff and Flannery (1996) found that raptors perching on wind turbines resulted in higher fatalities, and Nelson and Curry (1995) found a 54 percent reduction in perching with installation of perch guards. Using tubular rather than lattice towers, the bases of which provide raptors a convenient perch, would seem to be the most effective means of reducing perching. However, studies by Thelander and Rugge (2000) do not support this conclusion. These researchers found that turbines with tubular towers at the Altamont WRA had higher collision rates (0.22/year) than did diagonal-lattice towers (0.11/year) or vertical-axis turbines (0.19/year). Their studies suggested that slope, topography, and proximity to prey were more important factors in collisions than tower type. Orloff and Flannery (1992) reported the highest fatalities at horizontal-lattice turbines in the Altamont Pass WRA. However, Thelander and Rugge (2000) found higher fatality rates in those portions of the WRA where horizontal-lattice turbines were absent. Research and literature reviews by Morrison et al. (2007) suggest that specific tower types do not appear to have a substantial influence on fatalities, and instead conclude that placement of turbines relative to the slope is the primary factor, as discussed below.

Several researchers have found that the location of turbines relative to each other or to topographic features of the site can affect risk of collision, and that careful siting of wind turbines can reduce fatalities. Orloff and Flannery (1992) concluded that raptor fatalities at the Altamont Pass Wind Resource Area were higher for turbine strings near canyons and for

turbines at the ends of rows. Smallwood and Thelander (2004, 2005) found similar results, with fatalities related to turbine site characteristics and the position of turbines within a turbine string. Studies by Strickland et al. (2001) at Foote Creek Rim site, a flat-topped mesa with a very distinct rim edge, identified areas of high raptor use during the pre-permitting period. Approximately 85 percent of the estimated use of this site by raptors occurred within 50 meters of the edge of the rim. These high-use areas were avoided by the developer when turbines were sited. The final monitoring report for the Foote Creek Rim wind resource area (Young et al. 2003) noted that factors such as distance from rim edge to turbine did not appear associated with a higher probability of bird fatalities. Smallwood and Neher (2004) made similar findings at the Altamont Pass Wind Resource Area, concluding that raptors fly disproportionately more often on the prevailing windward aspects of slopes. When new turbines were installed at the High Winds project site in the Collinsville Montezuma Hills Wind Resource Area, Solano County, similar preventive action was taken to avoid placing turbines in risky topographic situations comparable to those observed in Altamont Pass (Kerlinger et al. 2006).

Smallwood and Thelander (2005) discovered significant associations between bird fatalities and the density of wind turbines on the landscape; sparser turbine spacing killed more birds, and more densely packed turbines killed fewer. Orloff and Flannery (1992) also found lower structure density to be associated with higher mortality, although Hunt (2002) speculated that turbines spaced farther apart might reduce golden eagle fatalities at the Altamont Pass Wind Resource Area.

Thelander and Rugge (2000) reported that approximately 24 percent of the turbines they studied accounted for 100 percent of the turbine-related fatalities. Fifteen of the turbine strings studied by Rugge (2001) were located in highly complex topographic areas, and were responsible for 60 percent of all raptor fatalities at the Altamont Pass Wind Resource Area (including 80 percent of the red-tailed hawk and 100 percent of the golden eagle fatalities). These data suggest that the placement of turbines relative to slopes and other topographic features is a crucial factor to consider in assessing and reducing collision risk.

Effect of Guy Wires on Risk

Most modern turbines do not use guy wires, but many of the meteorological (met) towers found at wind resource areas do. Guy wires clearly present a hazard to nocturnal migrants at communications towers; Longcore et al (2008) conducted a meta-analysis of the effect of guy wires, tower height, and lighting on nocturnal migrant collision risk at communications towers. They found that annual mortality of nocturnal migrants was significantly predicted by the number of guy wires on a tower. Less information is available on the effect of guyed met towers, which are considerably shorter than communication towers. Research in Europe (Winkelman 1992) and Minnesota (Johnson et al. 2000a) documented avian fatalities likely caused by guy wires supporting met towers. At the Foote Creek Rim WRA in Wyoming (Young et al. 2003) the carcass count beneath met towers was six times greater than at wind turbines of similar height.

In California, bird carcasses have been found beneath met towers as incidental finds. Orloff and Flannery (1992) found no fatalities at 48 met towers, most of which had guy wires, at the

Altamont Pass Wind Resource Area. In bird monitoring studies for the Shell Wind Energy project at Bear River Ridge in Humboldt County, surveyors found five dead birds beneath two guyed towers over the course of 36 surveys (Mad River Biologists 2006).

Kerlinger et al. (2007a, 2008, 2008a) conducted studies at 15 met towers at three project areas (Shiloh I, Shiloh II, and Hamilton) within and adjacent to the Collinsville Montezuma Hills Wind Resource Area in Solano County. Carcass searches were conducted approximately weekly, with search areas covering a radius of 50 meters from the tower. Unadjusted fatality rates at the three sites ranged from 2.5 fatalities/tower/year to 7.6 fatalities/tower/year, with passerines comprising the majority of fatalities.

Until these monitoring studies were conducted at Solano County, little systematic research had been done in the state on the collision risk posed by guy wires at wind resource area meteorological towers. Further research is warranted to determine if guy wires at met towers are responsible for substantial bird fatalities, and to determine if minimization measures (such as bird deterrents) might be effective in reducing collisions.

Assessing Indirect Impacts on Birds

In addition to the habitat loss and fragmentation resulting from construction of wind energy facilities, wind turbines can also have indirect adverse effects on birds by altering foraging behavior, disrupting breeding activity, or altering movement/migratory patterns. In the United States researchers have focused considerable attention on the indirect impacts of wind turbines on grassland birds, particularly Phasianids such as grouse. Some grouse species exhibit high site fidelity and require wide expanses of open habitat such as grasslands or sagebrush (Shuford and Gardali 2008). Lek, the traditional courtship display grounds of a number of grouse species, are consistently located on elevated or flat grassland sites with few vertical obstructions. Several studies indicate that certain grouse species strongly avoid certain anthropogenic features (e.g., roads, buildings, power lines, turbine towers), resulting in sizable areas of habitat rendered less suitable (Robel et al. 2004; Pitman et al. 2005). For most of California such impacts have not been a significant source of concern because the locations of proposed wind energy facilities have not overlapped with the range of the greater sage grouse, a lekking species which is also a California species of special concern. No new wind resource areas are currently proposed within this species' range, which consists of the northeastern Great Basin portion of California (eastern Siskiyou, Modoc, and Inyo counties) (Shuford and Gardali 2008).

Researchers have also documented displacement and changes in habitat suitability for grassland songbirds due to the proximity of wind turbines, where habitat suitability was indicated by the density of nesting pairs (Leddy et al. 1999). Erickson et al. (2003a) reported pre- to post-construction declines in densities of grassland nesting songbirds along transects oriented perpendicular to the wind turbine strings on the border between Oregon and Washington. Declines were as high as 40 percent for some songbirds and were strongest within the first 50 meters of transect. Kerlinger (2002) reported declines in the abundance of several species of forest nesting birds at the Green Mountain wind energy project in Vermont Green

Mountain. Those species that require large, unbroken tracts of breeding habitat decreased, and bird species usually associated with the edge of forests or forest fragments increased.

Few studies have investigated the relationship between nest site occupancy and the presence of wind turbines in or near the range of raptors. One of the few reports of avoidance of wind facilities by raptors occurred at Buffalo Ridge, where raptor nest density on 261 km² of land surrounding a wind facility was 5.94/200 km², yet no nests were present in the 32 km² wind facility itself, even though habitat was similar (Usgaard et al. 1997). Similar numbers of raptor nests were found before and after construction of Phase I of the Montezuma Hills wind project in Solano County, California (Howell and Noone 1992). A pair of golden eagles successfully nested 0.8 km from the Foote Creek Rim, Wyoming, wind facility for three different years after it became operational (Johnson et al. 2000b), and a Swainson's hawk nested within 0.8 km of a small wind plant in Oregon (Johnson et al. 2003a). In a survey to evaluate changes in nesting territory occupancy, Hunt and Hunt (2006) found that all 58 territories occupied by eagle pairs near, but not within, the Altamont Pass Wind Resource Area in 2000 were occupied in 2005.

Mabey and Paul (2007) provide a comprehensive literature review of the impacts (mortality, avoidance, reductions in nesting success and adult survival, and behavioral changes) of wind energy facilities on grassland and shrub-steppe avian species. They concluded that most studies they reviewed had multiple flaws in study design and methodology that reduced the strength of their conclusions and made comparisons or generalizations difficult. Few studies are currently available that would provide useful information as to whether installing wind turbines might significantly change patterns of bird migration, nesting, and foraging. Furthermore, few studies are available that would inform the establishment of appropriately sized buffers around nests of raptors or other breeding birds to avoid such impacts. Research is needed to assess which species are likely to benefit from buffer zones, and an appropriate size for such buffers. Such research would provide a useful tool for impact assessment and management.

Assessing Indirect Impacts on Bats

Bats may be attracted to some wind resource areas, and therefore be at increased risk of collision, because of modifications of forest structure and landscape resulting from wind facility construction. Bats are known to forage readily in small clearings (Hayes and Loeb 2007) like those that occur around turbines after construction. Both local populations of bats as well as migrants making stopovers may be attracted to areas cleared for turbine placement as they are to natural forest clearings. Studies have also suggested that many bat species use linear landscape elements, such as those created by roads built through forest, for successful foraging or commuting (Patriquin and Barclay 2003), echo-orientation (Verboom et al. 1999), and protection from predators or wind (Verboom and Huitema 1997). Forest edge effects created by clearing also may be favorable to insect aggregations and a bat's ability to capture them in flight (Verboom and Spoelstra 1999).

Rabin et al. (2006) studied how the noise of wind turbines affects California ground squirrels in the Altamont Pass Wind Resource Area of Northern California. The authors found that squirrels under the turbine sites exhibited elevated levels of vigilance and showed increased caution, and

suggested that the impacts of turbines on wildlife behavior should be considered during turbine siting.

In general, the indirect effects of wind energy developments on bird and bat populations have not been a major focus of interest or research at California wind energy developments as they have in other states and countries. This issue may become a higher research priority as more information is gathered on how California bird and bat populations are affected by wind facilities, and as wind energy development moves into new regions of the state.

Assessing Population Impacts for Birds and Bats

Most evaluations of wind-turbine-related avian fatalities have suggested that bird species colliding with wind turbines are common and not threatened at the population level (Nelson and Curry 1995; Osborn et al. 2000; Erickson et al. 2001; Strickland et al. 2001); however, no studies have specifically tested this hypothesis. McCrary et al. (1984a) estimated that as many as 6,800 birds, mainly passerines, are killed annually at the San Geronio WRA, but considered the fatalities to be relatively insignificant compared to the estimated 69 million birds migrating through the area each year. Johnson et al. (2000a) found a relatively low wind-turbine-related fatality rate for common, resident breeding birds and indicated that there would likely be no population consequences within the Buffalo Ridge WRA in Minnesota. Winkelman (1995) found that the Netherlands had some of the highest per-turbine fatality rates in the world, but considered this to be a less than significant biological problem for bird populations because the species that were killed were primarily common waterfowl and shorebird species.

While there is currently little evidence that wind energy development has negatively affected populations of birds, few studies have actually assessed the overall effects of wind turbines on the population viability of an individual species. Such studies require multi-year, intensive field efforts to provide data for calculating the relevant population parameters. One multi-year study was conducted in the Altamont Pass Wind Resource Area in Alameda County, California, to assess turbine collision impacts on the resident golden eagle population (Hunt and Hunt 2006; Hunt 2002). This seven-year demographic investigation involved aerial surveys to estimate survival among approximately 60 pairs of radio-tagged eagles. The study found that the breeding population of golden eagles within the vicinity of Altamont Pass WRA remained intact, but that to sustain the population an influx of recruits was needed to fill vacant breeding territories. The authors estimated that young from 167 breeding pairs of golden eagles were required to offset 50 blade-strike fatalities per year. At the current levels of eagle fatalities at the Alameda Pass WRA (Smallwood and Thelander 2004, 2005), the viability of the eagle population depends on adequate immigration from surrounding areas, making the population vulnerable to declines if fatalities increased for other reasons, or if reproduction decreased due loss of foraging habitat (Hunt and Hunt 2006). The 2005-2007 studies at the Altamont Pass WRA indicate an estimated average mortality rate of 80 golden eagles per year (Altamont Pass Avian Monitoring Team 2008).

No studies have assessed the impacts of wind facilities on bat population viability, but recent reports of large numbers of bats being killed at wind developments (e.g., Fiedler 2004; Kerns and Kerlinger 2004; Arnett 2005; Arnett et al. 2008) raise concerns about potential cumulative

impacts at the population level. Bats are long-lived mammals with few predators and low reproductive rates (Kunz et al. 2007). Sustained, high fatality rates from turbine collisions could therefore have potentially significant impacts on bat populations, and possibly increase the risk of local extirpation (Kunz et al. 2007). Currently the most basic demographic information is unavailable for any California bat population, making assessment of impacts to bat populations a speculative effort.

Based on the sparse data available on bat fatalities at California's wind resource areas, hoary bats are apparently the most common bat carcass detected beneath wind turbines, with fatalities of western red, Mexican free-tailed, and silver-haired bats also reported. No California bat species are listed as threatened or endangered, but western red and hoary bats are considered species of special concern by the state Department of Fish and Game (www.dfg.ca.gov/wildlife/species/ssc/index.html). The Western Bat Working Group (www.wbwg.org) has categorized western red bats as a high-priority species (imperiled or are at high risk of imperilment) and hoary bats and silver-haired bats as medium-priority species (warranting closer evaluation, more research, and conservation actions).

Bats collected during carcass counts can provide information for advancing knowledge about the geographic source and abundance of resident and migratory populations. Tissue samples can be used for analysis of genetic variation and population structure, for assessing population size using DNA markers, and for assessing the geographic origin of migrants based on stable isotope and genetic analysis (Simmons et al. 2006). The American Museum of Natural History in New York serves as a repository for carcasses and tissues collected from dead bats recovered beneath wind turbines or from other sources. Laboratory research is needed to assess the population structure.

The cumulative impacts of wind energy on bird and bat populations have also been unstudied, but given the projected development of wind energy resources, biologically significant cumulative impacts are likely for some species (Arnett et al. 2007). Stewart et al. (2004) conducted a meta-analysis of bird mortality for studies conducted throughout the world. Findings suggest that wind farms may reduce the abundance of many birds, and that this impact may become more pronounced with time. The authors note that their results should be interpreted with caution given the small sample sizes and variable-quality data for the studies in the meta-analysis. They note that long-term, well-replicated randomized studies with established baselines and comparators are required to improve the evidence base before making conclusions about the cumulative impacts of wind energy development on bird populations, recommending a precautionary approach and avoidance of siting wind farms near populations of special-concern birds.

Morrison and Pollock (1997) reviewed the major factors that can influence the persistence of a wild population. They note that in some populations even a relatively minor change in survivorship can have substantial impacts, and emphasize the importance of determining survivorship in evaluating the effects of wind energy developments on birds. Morrison and Pollock (1997) and Morrison et al. (2007) concluded that Population Viability Analysis (PVA) provides a useful framework to advance understanding of the processes driving population

responses to perturbations such as wind developments. PVA is an approach that can be used to predict effective population size or time to extinction based on demographic data, genetics, and life history attributes. A PVA analysis requires population-level data that are time consuming and costly to collect. Morrison and Pollock (1997) therefore recommend prioritizing selection of species that merit such an extensive analysis, the top two priorities being locally rare populations of an overall rare species, and a locally common population of an overall rare species.

A preliminary assessment would be useful to evaluate the potential for population level effects of wind energy development on special status bird and bat species in California. However, conducting a PVA and the intensive field efforts required to collect data for such an analysis is not envisioned as a short-term goal in this Roadmap. Furthermore, many of the species impacted by wind energy projects are widespread and migratory, crossing multiple state and national borders, which increases the complexity of assessing population impacts and enlarges the scope of the analyses beyond California. PIER-supported long-term studies of cumulative population impacts would need to focus on research that would demonstrably benefit California's resident and seasonal bird and bat populations at risk of such impacts.

Post-Construction Monitoring/Measuring Effects of Operations

Assessing direct impacts of wind turbines involves counting the carcasses of birds and bats beneath the turbines. Carcass counts provide an estimate of fatalities resulting from wind turbine operation, and can offer information about the relationship between fatalities and measured variables of the wind turbines and the environment. Carcass counts need to be repeated over relatively long periods because wind turbine fatalities vary seasonally, and because they are relatively rare events from a statistical perspective. In addition, corrections need to be made to adjust for significant sources of potential bias in the carcass searches. To make a realistic fatality estimate, the number of carcasses found during a search needs to be added to an estimated number not found because of removal by scavengers, carcasses missed by the searchers, and carcasses that fell outside the search area.

While methods for conducting carcass searches at wind energy facilities are relatively well established (Anderson et al. 1999; Morrison 1998, 2002), much uncertainty remains on how the frequency of carcass searches, the size of the search plot, and adjustments for scavenging and searcher bias affect the fatality data. Different investigators vary in the assumptions and adjustment formulae they apply, and therefore can arrive at different fatality estimates with the same data set. The following discussion describes the research and monitoring studies that provide information on how these variables (size of search area, frequency of searches as it relates to scavenger removal, searcher variability and error,) and the formulae used to integrate these variables affect the estimate of fatality rates.

Size of Search Area

The size of the area searched for carcasses influences the fatality estimate. Many recent studies have used rectangular search areas with the distance to the boundary of the area at least equal to the maximum tip height of the turbine, and have found that most fatalities occur in this area (Kunz et al. 2007). Smallwood and Thelander (2004, 2005) found that 87 percent of bird carcasses were located within 50 meters (164 feet) of the turbine. The Smallwood and Thelander studies were mostly on small, older-generation turbines. The proportion of fatalities that land outside of search plots can be estimated by using the distribution of fatalities as a function of distance from turbines (Kerns et al. 2005). Bats tend to fall close to the turbines, and most studies have shown a tighter distribution of bat fatalities around the turbine compared to birds (Kerns et al. 2005; Kerlinger et al. 2008).

In their monitoring studies at the Buffalo Mountain wind farm in Tennessee, Fiedler et al. (2007) found the average distance of bat carcasses from the V47 turbines (290 feet from base to rotor tip) was 72.5 ± 9.5 feet (SE, $n = 20$), and 78.3 ± 2.3 feet (SE, $n = 218$) from the V80 turbines (395 feet from base to rotor tip).

Studies by Kerlinger et al. (2006, 2008) at High Winds and Shiloh I on new-generation turbines in the Collinsville Montezuma Hills Wind Resource Area in Solano County exemplify the difference search area makes in the number of carcasses found. The search area for High Winds was a 75-meter radius from the tower (total search area = 34,636 m²) compared to the 105-meter radius (total search area = 17,671 m²) used for the similarly sized turbines at Shiloh I. Shiloh I had twice the adjusted raptor fatality rate per MW as High Winds (0.80 fatalities/MW/year versus 0.40 fatalities/MW/year), and the authors attributed much of this difference to the larger search area for Shiloh I. Even the 105-meter search area missed some of the carcasses; Kerlinger et al. (2008) report that out of 396 bird and bat carcasses found at Shiloh I, 14 were found beyond the search area boundaries. A golden eagle, which was crippled but not immediately killed by a wind turbine, was among these 14 incidental finds.

Research is needed to determine the range of distances that carcasses fall from the turbines as a function of species, turbine size, and topography. While some of this information might be extracted from existing studies, new field research is needed to determine an optimally sized search area that is both cost-effective and accurately encompasses most of the fatalities.

Frequency of Searches and Scavenger Removal Bias

Estimates of fatalities must be adjusted to reflect the proportion of carcasses removed by scavengers and therefore undetected during the carcass search. The scavenging rate, also called carcass removal, should factor in the frequency of the carcass searches because searches conducted at infrequent intervals in project areas with high scavenging may produce highly biased estimates of fatalities (Morrison 2002). Because adjustments for scavenging can dramatically change the estimate of fatality rates, it is important that researchers adequately account for all the variables that can affect scavenging when they conduct trials of scavenging rates.

Wide variation exists in estimated scavenging rates at wind resource areas throughout the country. Schmidt et al. (2003) found 52 percent of bird carcasses remained untaken through 21 days at the National Wind Technology Center near Boulder, Colorado. Johnson et al. (2002) reported the number of days to bird carcass removal at Buffalo Ridge, Minnesota, averaged 7 days. Howell and DiDonato (1991) reported the number of days to bird carcass removal in the Altamont Pass Wind Resource Area averaged 4.2 days. Orloff and Flannery (1992) found scavengers removed 43 percent to 56 percent of small raptor carcasses and 13 percent to 15 percent of medium-sized raptor carcasses within 7 days at the APWRA. No eagle carcasses were removed by scavengers during their study.

Smallwood et al. (2008) conducted a 290-day scavenging study in the Altamont Pass Wind Resource Area using remote cameras placed near randomly selected wind turbines. The remote cameras could identify exact times of removal and the species responsible for removing the carcasses. One to five carcasses at a time were placed volitionally at intervals throughout the entire 290 days of the scavenging study. The goal of placing just a few carcasses at a time was to prevent scavenger swamping and to more realistically simulate the deposition of bird fatalities from wind turbines. The mean time to a scavenging event in which the scavenger did not leave any evidence of the carcass behind was 4.16 d (SD = 5.21, N = 36). These researchers found that of the 63 carcasses sufficiently monitored, 57 percent were removed without leaving a trace in the immediate turbine search area.

Scavenging trials have shown that scavenging rates can vary depending on the time of year they are conducted, the size of the carcass used, and the number of carcasses put out at any one time during the trial. Erickson et al. (2003a) found scavenger removal fastest during spring and fall and slowest during winter and summer at the Stateline Wind Project in Oregon. They found 80.2 percent and 58.6 percent of small and large bird carcasses removed after 40 days, respectively; the average number of days to carcass removal was 23.1 for small birds and 42 for large birds. Erickson et al. (2000) reported average removal times of 26.78 days for large carcasses, and 23.4 for small carcasses at the Vansycle Wind Project in Oregon. Researchers have also reported that scavenging rates can vary over time because scavengers can learn of the presence of available carcasses, causing an increase in scavenging. Kerns et al. (2005) reported some scavengers, such as the common raven, learn quickly of carcass availability. At Searsberg, Vermont, Kerlinger (2002) found 20 percent of the 20 surrogate bird carcasses used for the trial disappeared within 7 days, 34 percent within 14 days, and 65 percent within a month during trials in September. In the July trial, 15 percent of the 20 carcasses disappeared by 2 days, and 80 percent by 65 days.

Researchers typically conduct scavenger trials using surrogate carcasses because large quantities of dead raptors, songbirds, and bats are difficult to come by for large-scale studies. The characteristics of the surrogate carcass may substantially affect scavenging rates, including such factors as fresh versus frozen, or wild/native versus domestic/nonnative species. Many studies have used house sparrows as surrogates for small birds and bats during carcass removal trials, and rock pigeons for medium-sized birds (Erickson et al. 2001; Morrison 2002). Young et al. (2003) used house sparrows and juvenile quail as surrogates for small birds, rock pigeons for medium-sized birds, and mallards for large birds. They reported mean lengths of stays of 13, 37,

and 29 days for small, medium, and large birds, respectively. Orloff and Flannery (1992) found non-raptor wild bird carcasses were taken more frequently than raptor carcasses, and that no eagle carcasses were removed by scavengers during their study. Howell and Noone (1992) found that frozen raptors from rehab centers were not removed when they were large bodied, whereas 75 percent were removed when they were small bodied.

Surrogate birds that have been frozen may differ in their attractiveness to scavengers, as may domestic surrogates such as chickens. Kerns et al. (2005) reported faster removal of fresh carcasses compared to frozen at the Mountaineer Wind Energy Center. Orloff and Flannery (1992), in preliminary trials at the Altamont Pass Wind Resource Area, found that intact brown chicken surrogates were scavenged at a higher rate than wild bird carcasses (Orloff and Flannery 1992). Anderson et al. (2005) found mean removal time was 2.12 days for large carcasses and 3.1 days for small carcasses at Tehachapi Wind Resource Area in Kern County, California. These researchers cautioned that the scavenger removal trial may have been biased because the surrogates they used—brown chickens and chicks—were more attractive to scavengers than the species normally killed by wind turbines.

Researchers have questioned the use of small birds as bat surrogates (Kerns et al. 2005). However, Erickson et al. (2003) and Johnson et al. (2003a) used bat carcasses which were likely killed the previous night and found similar or lower scavenging rates on these bat carcasses compared to small bird carcasses. In contrast, Kerns et al. (2005) reported significantly lower scavenging rates on birds compared to both fresh and frozen bat carcasses at the Mountaineer Wind Energy Center in West Virginia; here, scavengers removed 25 percent of bats in 9 hours, 35 percent in 1 day, and 68 percent in 3 days. However, Fiedler (2004) and Fiedler et al. (2007) conducted scavenging bias trials during the first phase of development at the Buffalo Mountain Energy Center in Tennessee and found no difference between bird and bat carcasses for searcher efficiency or scavenging time.

Many questions remain on how the elements of scavenging trials (size of the search area, study design, type and deployment of surrogate carcasses, and search intervals) affect the accuracy of the carcass count and the corrections that are applied to arrive at a fatality rate. These questions are amendable to experimental investigation and will be addressed by PIER's proposed research.

Background Mortality

Some bird and bat casualties discovered during searches and used in fatality rate estimates may not be related to wind turbine impacts. Natural bird and bat mortality and predation occur in the absence of wind turbines, and a number of studies have quantified the level of background mortality at proposed or operating wind resource areas. Nicholson (2003) searched three control sites with a 50-meter radius 150 times and found two apparent natural bird fatalities or about 0.00566 natural bird fatalities per hectare (ha) of searching. Schmidt et al. (2003) searched for fatalities on and off the National Wind Technology Center in Colorado, and found no fatalities in the ten 0.79-ha plots off the wind energy facility. He only found six fatalities over a two-year period near the turbines and two of these appeared to be caused by guy wires. During a wind-avian study at the Buffalo Ridge Wind Resource Area in Minnesota, Johnson et al. (2000)

conducted 2,482 searches in reference plots and found one naturally occurring fatality for every 78 person-hours spent searching.

Several background mortality studies have also been conducted in California. Kerlinger et al. (2006) found no fatalities in 159 ha of pre-permitting turbine sites at the High Winds power project in Solano County. After construction of 90 turbines at the site, searchers counted 163 dead birds and 116 bats under the turbines during a two-year period. Anderson et al. (2005) studies at the San Geronimo WRA found the highest level of mortality in plots located 400 to >1,000 meters from wind turbines, but a large proportion of birds found on these plots appeared to have been killed by wind farm infrastructure, such as power lines and roads.

Based on the data collected thus far, background mortality does not appear to be a significant source of error in estimating fatalities at wind resource areas, and may not merit research attention. If background mortality is of concern at a particular proposed wind energy project, a “clean sweep” of carcasses can be conducted at the proposed sites before operations monitoring, and/or at control sites without turbines during project operation.

Searcher Efficiency

Another major source of bias in estimating fatality rates is searcher efficiency, which is the rate at which human searchers detect bird and bat carcasses. Searcher efficiency, also called observer bias, will vary depending on inherent individual differences (visual acuity, physical vigor, motivation, experience, and training of the searcher), differences in field conditions (weather, lighting, and vegetation density and height), and characteristics of the carcass (color, size, freshness of the remains) (Wobeser and Wobeser 1992; Anderson et al. 1999; Morrison 2002). For example Arnett (2005) found that searchers found only about half of the birds or bats during searcher detection trials in West Virginia. Johnson et al. (2002) reported only 38.7 percent searcher detection of bird carcasses at Buffalo Ridge, Minnesota. Kerlinger (2002) reported a searcher detection rate of 55 percent at Searsburg, Vermont. Estimates of animal fatalities in wind developments are therefore biased by inefficiencies of observers, and researchers typically quantify and correct for these variations by conducting searcher efficiency trials.

Searcher detection trials consist of planting carcasses throughout the study area without the searchers being aware that trials will be conducted. Few studies have documented the effect of carcass placement on searcher efficiency. Orloff and Flannery (1992) warned that conducting trials by placing intact dead birds in the search area may not replicate the appearance of wind-turbine-killed birds because collisions knock feathers off and sometimes dismember the bird or leave it splayed.

Correction factors for searcher efficiency may need to vary depending on the size of the carcass because several studies have indicated large carcasses are more easily detected than small (Gauthreaux 1995). Orloff and Flannery (1992) reported searcher detection for raptors and other wild birds at 100 percent for large birds, 75 percent for medium-sized birds, and 69 percent for small birds in the Altamont Pass Wind Resource Area. Young et al. (2003) reported searcher detection rates of 59, 87, and 92 percent of small, medium, and large birds, respectively, at Foote

Creek Rim in Wyoming. Kerns et al. (2005) reported searcher detection of bat carcasses at 43.6 percent at the Mountaineer Wind Energy Center in West Virginia.

Using trained dogs during the searches can significantly increase searcher efficiency, especially when vegetation is dense (Arnett 2005; Gutzwiller 1990; Homan et al. 2001. Erickson (2005 cited in Kunz et al. 2007) reported dogs found bats 2–4 times more often than did human searchers without dogs. Arnett (2006) found that trained dogs were able to find 71 percent of planted bat carcasses during searcher efficiency trials at the Mountaineer site in West Virginia and 81 percent at the Meyersdale site in Pennsylvania, compared to 42 percent and 14 percent, respectively, for human searchers (Arnett 2006).

Formulae for Correcting Carcass Counts

Researchers have used a variety of methods and formulae to adjust their fatality counts with the estimated rates of scavenger removal and searcher efficiency. Gauthreaux (1995), Orloff and Flannery (1992), and Smallwood and Thelander (2004) use a simple formula to calculate the corrected fatality rates using correction factors based on field data for scavenging rates and searcher efficiency. Carcass count data are adjusted with estimated rates of scavenger removal and searcher detection with this formula:

$$M_A = \frac{M_U}{DR}$$

where M_A and M_U are adjusted and unadjusted mortality estimates, respectively, D is the search detection rate and R is the scavenger removal rate. The form of this equation is nonlinear. Johnson et al. (2003) and others have used a different formula to adjust fatality counts:

$$M_A = \frac{N \times I \times C}{k \times t \times p},$$

where N is the number of wind turbines in the wind project, k is the number of wind turbines sampled, I is the search interval in days, C is the number of fatalities counted, t is the mean carcass removal time in days, and p is the observer efficiency rate. This formula attempts to account for the likelihood the fatalities found during standard searches could have been caused during any time since the last fatality search. The equation assumes carcasses are removed by scavengers at an exponential rate.

Shoenfeld (2004) provides a model and simulations for the derivation of an adjusting constant that reflects both observer bias and scavenger bias. Shoenfeld (2004) offers an estimate of the uncertainty in the corrected fatality rates, but the other formulae and models do not. Warren-Hicks and Newman (2008) note that field trials to generate observer and scavenging bias constants that plug into these equations do not usually address the interactions that can occur between these two sources of error. In that circumstance, the probabilities of observer bias and scavenging bias in the denominators of the two equations above are not independent. Schoenfeld (2004) also points out that the observer bias and searcher bias estimates are typically derived from small samples of carcasses in field studies, which are usually performed concurrently. Appendix G in the *Guidelines* (CEC and CDFG 2007) recommends that field trials

on search efficiency and scavenging be designed so that these sources of error are independently estimated. However, not all monitoring reports provide sufficient information about their methods to determine if this step was taken.

Researchers at the Altamont Pass Wind Resource Area have suggested an approach that addresses the potential interdependence of these two factors (Schwartz 2008). They recommend replacing separate estimates of searcher efficiency and scavenger efficiency with a combined detection probability. Schwartz (2008) has proposed a pilot study for the APWRA monitoring program to estimate species-specific bird mortality with the intent of providing an empirically based estimate of overall carcass detection probability under all possible searcher efficiency/scavenger rate permutations.

The models and correction formulae used or proposed by researchers rely on a number of untested assumptions and sources of bias that can significantly alter the estimated fatality rate. Smallwood (2007) reviewed published studies and monitoring reports in which researchers used a variety of methods to estimate searcher efficiency and scavenger rates and calculate estimated fatalities. He concluded that most fatality estimates at wind resource area were highly imprecise. Smallwood (2006) describes in detail some of the potential biases in estimating carcass count data, the most significant of which result from design and implementation of scavenger removal trials and searcher efficiency trials.

Identifying true differences in fatality rates at wind resource areas will require consistent assumptions and adjustments applied to the carcass count. Chapters 4 and 5 discuss the field studies and modeling needed to assess and account for the inherent biases of the formulae assumptions used by researchers.

Metrics for Fatality Estimates

Earlier monitoring reports often presented fatality rates on a per-turbine basis, but more recent reports often use a metric of the number of fatalities per megawatt (MW) of installed capacity per year (Smallwood and Thelander 2004, 2005; National Research Council 2007). This metric avoids the problem of comparing turbines with substantially different rotor-swept areas and capacities. This problem is particularly pronounced in situations like the Altamont Pass Wind Resource Area where there is extreme variability in the number of functional turbines and the rated capacity from year to year, season to season, and even daily (Altamont Pass Avian Monitoring Team 2008a).

The MW figure represents the nameplate capacity for the turbine and not the actual amount of MW produced by a turbine. A measure of MW production that incorporated operating time would provide a much better, more accurate metric for comparison purposes because two identical turbines of the same nameplate capacity operating at different percentages of time but with similar bird kills could skew risk assessments (Smallwood and Thelander 2004). However, information about MW production and operating time is often difficult to secure at many wind energy facilities, so the MW of installed capacity per year remains the option currently used most often by researchers.

Impact Avoidance and Mitigation

Relatively few studies have conclusively demonstrated that avoidance and mitigation strategies have reduced impacts to birds and bats as expected, and some mitigation measures currently being implemented are based on anecdotal information (Johnson et al. 2007). The term “mitigation” in the context of wind turbine–wildlife interactions is often used loosely to encompass a variety of actions, ranging from careful placement of turbines within a wind resource area (micro-siting), to making modifications to turbine operations or to the habitat around turbines.

Wind energy developers must typically make decisions about proposed wind resource area siting and turbine types long before information from biological studies are available. Therefore, discussion of the effectiveness of turbine configuration and repowering in reducing risk to birds and bats was addressed earlier in this chapter. The mitigation topics discussed in this section include alerting and deterring mechanisms at turbines to minimize risk, operations modifications, habitat management, and compensatory mitigation.

Alerting and Detering Mechanisms

Visual Deterrents to Reduce Bird Fatalities

Several lab studies have analyzed the causes of bird collisions with wind turbine blades and evaluated visual deterrents based on the results of the analysis. Researchers have hypothesized that birds may collide with turbines, despite their excellent visual acuity, because of “motion smear,” in which an object becomes progressively blurred as it moves across the bird’s retina with increasing speed. Several studies have assessed the ability of birds to see turbine blades at varying velocities, with varying patterns and colors, and with and without lateral blade tip devices. The data collected were used to model the distances at which patterns maintain their visibility for different turbine diameters and rotation rates.

Howell et al. (1991) conducted a field study consisting of a randomly selected sample of 25 turbines with blades painted an alternating pattern of red and white and 50 control turbines at the Altamont Pass WRA. Preliminary results indicated fewer bird fatalities at turbines with painted rotors, but the small sample size precluded any definitive conclusions. Young et al. (2003a) examined the effects on bird use and mortality of painting wind turbine blades with UV-reflective gel at Foote Creek Rim Wind Plant in Wyoming and found no significant differences between bird fatalities, use, or risk between blades with UV-reflective paint and those with conventional paint. The authors concluded that a different study design with a larger sample size of turbines and more observations might have allowed more conclusive statistical inferences of the potential value of UV-reflective paint as a deterrent. Other untested techniques have been proposed to reduce nocturnal avian collisions with wind turbines, including use of luminescent or phosphorescent marking materials visible to nocturnal birds (Avery 1978).

Hodos et al. (2001) found that motion smear could be reduced under laboratory conditions, and suggested that a single, solid-black blade paired with two blank blades—or possibly a single, thin-striped blade paired with two blank blades—would be the most visible visual deterrent to birds in the field Hodos (2003). McIsaac (2001) laboratory tests on American kestrels found that

applying high-contrast patterns to turbine blades might increase the birds' ability to distinguish individual blades. Their preliminary results suggested that a single, solid-black blade, paired with two white blades (inverse blade pattern) could effectively reduce visual smearing of blades. These results were produced under laboratory conditions that provided an artificially high-contrast background.

Altamont Wind Incorporated (AWI) has recently conducted some informal field trials of Black Blade Technology, which involves painting one of the three wind turbine blade solid black and leaving the other two white (AWI 2007). These information field trials were promising, and AWI proposed additional field tests of the technology at the Altamont Pass Wind Resource Area. The Science Review Committee for the Altamont Pass Wind Resource Area recommended a follow-up study of AWI blades using 135 turbines in the control group (unpainted) and 170 painted turbines as the sample size, but this study has not yet been implemented because of cost and operational concerns. AWI's affiliate possesses the exclusive rights to use (and sell/license) the Black Blade Technology, including the ability to install such painted blades on wind turbines in the APWRA, under an exclusive license agreement executed with the University of Maryland, the holder of a U.S. patent covering this technology. Research opportunities are therefore limited by investigator's access to the Black Blade Technology.

Auditory Deterrents to Reduce Bird and Bat Fatalities

No research has been conducted on auditory deterrents to birds approaching wind turbines. Audible devices to scare or warn birds have been used at airports, television towers, utility poles, and oil spills, but most studies have found that birds become habituated to these devices (Erickson et al. 1999). Experiments have determined that birds can detect pulsed microwave signals, and Kreithen (1996) suggested the use of pulsed microwaves to warn birds of hazardous obstacles. However, this microwave signal does not provide warning to a bird that an object is dangerous, only that it is present. Instrumentation for this technique has yet to be fully developed (Johnson et al. 2007).

Dooling and Lohr (2001) conducted studies suggesting that minor modifications to the structure of turbine blades could make them more audible to birds. Dooling notes that birds have a narrower range of hearing than humans do, and suggests that in windy conditions birds cannot hear the noise from wind turbine blades as well as humans can. Adding an acoustic cue to turbines in the range of best hearing for birds (2–4 kHz) would not substantially increase noise levels to human perception but might help birds hear the blades. The underlying assumption is that birds are less likely to collide with something they can hear.

Dr. Ed Arnett with the Bats and Wind Energy Cooperative (BWEC), Dr. Szewczak from Humboldt State University, and acoustic and neurological expert Dr. Cindy Moss from the University of Maryland are evaluating acoustic deterrents to reduce bat fatalities at wind facilities (NWCC 2007; Arnett et al. 2007; BWEC 2008). These scientists hypothesize that the best results for bat deterrence may come from high-amplitude sonar "jamming" sounds, taking a lesson from moths that can perform this to deter bats. They also hypothesize a threshold effect in which some level of ultrasound may attract curious bats, but a higher level will cause bats to exhibit avoidance because they cannot hear anything except what is emitted from the deterring

device. To date, results from laboratory tests indicate that captive-raised big brown bats generally avoided the deterring device during flight trials. Additionally, big brown bats trained to “hawk” mealworms during feeding trials in the lab exhibited no success at capturing prey when the device was turned on.

Another means of bat deterrence has been posited by Nichols and Racey (2007), who have predicted that bat activity would decrease in the vicinity of radar installations based on observations of reduced bat activity at the Aberdeen Air Traffic Control radar station. They found that bat activity and foraging effort per unit time was significantly reduced in habitats exposed to an electromagnetic field greater than 2V/m. They suggested that most of the behavioral changes from exposure to radio-frequency radiation were due to the risk of thermal induction and hyperthermia.

The BWEC work (frequency jamming) on auditory bat deterrence is a promising line of inquiry and one of the few for which active research is currently underway. A number of technical difficulties would need to be overcome to make this a viable bat deterrence tool, including the rapid attenuation of high-frequency sound (Weller pers. comm. 2008).

Operations Modifications

A number of researchers (Crockford 1992; Orloff and Flannery 1992; Gill et al. 1996; Barrios and Rodriguez 2004; Smallwood and Thelander 2004, 2005) have suggested reducing collision risk by suspending operation of problem turbines under certain circumstances. The critical shutdown times might be seasonal, such as during migration, or during periods of adverse weather combined with migration. No studies have been completed that assess the effectiveness of such shutdowns at reducing fatalities, but one is currently under way at the Altamont Pass Wind Resource Area. The seasonal shutdown is part of the November 6, 2006, Settlement Framework that resolved the litigation concerning bird mortality from wind turbine collisions, and specified the operators were to “*cease operations for approximately ½ of existing (non-repowered) operating Applicable Turbines between November 1, 2007 and December 31, 2007 and the remaining ½ of existing (non-repowered) operating Applicable Turbines between January 1, 2008 and February 28, 2008.*” The timing of the operation curtailment was designed to accommodate the period when use by migrating birds is high and power production is low. Final results are not yet available documenting the results of the operation curtailment.

Another study may soon be under way to evaluate the effects of seasonal shutdowns of turbines in Oaxaca, Mexico, at the Isthmus of Tehuantepec (NWCC 2007). Three seasons of field studies at this proposed wind resource area, the largest in Latin America, revealed more than four million migratory raptors passing the potential turbine sites. The raptors, which included the broad-winged hawk, Mississippi kite, and Swainson’s hawk, were observed flying at elevations that put them at collision risk (NWCC 2007). Rafael Villegas-Patracá and his colleagues will monitor the effects of a mitigation strategy to shut down the turbines for three weeks during the prime migration period (NWCC 2007).

Another operations modification that may reduce collision risk for bats is the possibility of “feathering” wind turbines on low-wind nights. Feathering means pitching the turbine blades

parallel to the direction of the wind to make them stationary. Kerns et al. (2005) found the majority of bat fatalities at Mountaineer and Meyersdale occurred on low-wind nights, when power production appeared insubstantial but turbine blades were still moving. Horn et al. (2008 cited in Arnett et al. 2007) had similar results, finding a negative relationship between the numbers of bat passes observed from infrared thermal images and average nightly wind speed at the Mountaineer facility. In Germany, Brinkman (2006) observed higher bat activity via thermal imaging when wind speeds were between 3.5 and 7.5 m/s, but also observed some activity up to 10.9 m/sec. At Buffalo Mountain in Tennessee, Fiedler (2004) found a negative relationship between bat fatality and wind speed and temperature. Weller (2007) found similar results at his studies in Southern California. Acoustic monitoring of bats at proposed wind facilities corroborates these findings and indicates that bat activity generally is higher on low-wind nights (Reynolds 2006; Arnett et al. 2006). Experiments are needed to test the hypothesis that feathering turbines on low-wind nights would reduce bat fatalities.

Brown and Hamilton (2006) conducted an experiment in September 2005 at the Summerview wind power project in Alberta, Canada. The goal was to assess the effects of modifying the cut-in wind speed from the rated 4 m/s to 7 m/s to see if they could reduce the rate of bat collisions at wind speeds of 4–6 m/s. After operating parameters were changed, the bat fatality rate was significantly lower at turbines that had their rotors braked and locked compared to those operating normally under low-wind conditions ($\chi^2 = 7.74$, $df = 1$, $P = 0.0054$). Researchers in Canada and Germany also found bat fatalities were reduced at turbines with higher cut-in speeds (Weller pers. comm.).

Further research is needed on the efficacy of operational modifications in reducing bat and raptor fatalities. Such research would need to be accompanied by an analysis of the costs of these operation changes in terms of lost revenue from decreased power production and potential penalties for failing to meet production targets.

Habitat and Prey Abundance Modifications

Hunt (2002) and Smallwood et al. (2001) suggested that reducing prey populations in the vicinity of wind turbines at the Altamont Pass Wind Resource Area might reduce high-risk foraging activities for raptors. Prey densities are apparently highest along roads and turbine pads, the latter of which would exacerbate collision risk. Thelander and Smallwood (2007) found that the degree of clustering of pocket gopher burrows better explained the variation in fatality rates of red-tailed hawks than did turbine or tower type, tower height, or other hardware features. Hoover (2002) also found that prey availability was a contributing factor to raptor deaths at Altamont Pass, although not necessarily the primary one.

Suggested methods for reducing prey abundance included modifications to grazing regimes or revegetation in the vicinity of turbines with high-statured plants, both of which would make the immediate vicinity of the turbines less attractive to gophers. Recommendations have also been made for rodent abatement, but these measures could directly or indirectly impact special-status species such as the San Joaquin kit fox, burrowing owls, and badgers. Studies by Smallwood and Thelander (2004, 2005) concluded the rodent control program had made little

difference to golden eagle site utilization or mortality, and may have exacerbated mortality of red-tailed hawks.

Studies conducted in 2006 and 2007 on East Bay Regional Parks District property in the Altamont Pass Wind Resource Area addressed the question how different land management practices (sheep versus cattle grazing) might reduce raptor collisions by modifying the distribution of small mammals in the vicinity of turbines (Smallwood et al. 2008). Variable weather conditions during the two years of the study, which included an extremely wet and then a dry year, rendered the results of the study inconclusive with respect to how grazing management might reduce raptor fatalities. However, these researchers found that for proposed wind resource areas that support prey populations and raptors that hunt them, raptor use of declivity winds (strong winds passing over ridgetops as they are forced upslope) was a more important factor in drawing the raptors to wind turbines than the distribution of prey populations (Smallwood et al. 2008).

Smallwood and Thelander (2004, 2005) also suggested habitat improvements away from the wind resource areas to draw raptors away from the high-risk areas. Such enhancements could occur by increasing ground squirrel populations on neighboring ranch lands. A similar approach has been used to reduce waterfowl damage to domestic crops by planting “lure crops” to attract birds away from the domestic crops (Johnson et al. 2007). Studies for the Bonneville Power Administration (Erickson et al. 2002) in Oregon provide another example of a mitigation measure that recommends reducing available food in the vicinity of wind turbines. To minimize the collision risk for bald eagles, which often scavenge on carcasses in the winter months, it was recommended that dead cattle or other large sources of carrion be immediately removed from the wind resource area.

Permits for wind energy projects sometimes contain conditions such as those described above or require on-site habitat modification, such as moving rock piles that might attract rodents away from turbines and constructing tower pads to prevent under-burrowing by small mammals (Solano County 2006). However, little systematic research has been conducted to assess the effectiveness of these measures in reducing raptor fatalities.

Compensatory Mitigation

Compensatory mitigation is a common approach used to offset unavoidable impacts to biological resources. The goal of such compensation is typically to conserve habitat off-site to produce a number of birds or bats at least equal to the number killed by the wind turbines. Such off-site mitigation could consist of conservation, protection, and enhancement of essential habitat for breeding or foraging. The challenge for developing compensatory mitigation for wind turbine impacts is to establish a biologically meaningful nexus between the level of impact and the amount of mitigation. Unlike habitat impacts, in which an acre of habitat lost can be compensated with an appropriate number of acres of habitat protected or restored, bird and bat collisions with wind turbines are impacts that do not suggest an obvious compensation ratio.

Relatively few compensatory mitigation approaches were applied in the earlier days of wind energy development, but has become an increasingly common method for offsetting impacts

that cannot be avoided. The Nine Canyon wind power project in Washington specified payment of \$75/turbine/year for the life of the project to be used for shrub-steppe conservation (Erickson et al. 2003). Permit conditions for the Shiloh I and II projects at the Collinsville Montezuma Hills Wind Resource Area in Solano County called for the wind energy developer to purchase at least 146 acres of off-site conservation land in fee-title and/or easement for open space (Solano County 2006). The purpose was to provide a protected area suitable as breeding and foraging habitat for raptors impacted by the project, such as the golden eagle and red-tailed hawk. The 146 acres was the equivalent to the total rotor-swept area for the 88 proposed turbines in the Shiloh II project. Similarly based off-site mitigation for acquisition or conservation easement of 120 acres of breeding and foraging habitat was required for the Shiloh I project.

Potential impacts to listed species can increase the compensatory mitigation obligations. The CDFG required the Hatchet Ridge Wind Energy Project in Shasta County to mitigate for potential impacts to bald eagles and sandhill cranes with the acquisition, enhancement, or preservation of sufficient offsite breeding habitat at a 2:1 ratio of potential mortality (Shasta County 2008). The mitigation requirements also included a contribution of \$100,000 to a reputable land trust or conservation program approved by CDFG and USFWS for the purpose of off-site preservation and enhancement of bald eagle habitat.

Research efforts can make some contribution to developing a scientifically sound, biologically based mechanism for offsetting bird and bat mortality, assessing the biological nexus between bird and bat fatalities and proposed mitigations (for example, habitat enhancements), or testing the value of those already established. The California Department of Fish and Game is currently considering development of a compensatory mitigation policy—including metrics and recommendations for connecting the impact with the mitigation—for bird and bat impacts resulting from wind energy development (Flint pers. comm.). An appropriate long-term research goal is evaluating the effectiveness of the compensatory mitigation measures in offsetting impacts to impacted species.

The PIER Focus

California's wind energy development is expected to expand in the next two decades, particularly in the Tehachapi and in Mohave wind resource areas (Brower 2007). In addition, existing wind resource areas that use older, inefficient turbines are repowering with much larger, higher-capacity turbine designs. Resolving the many uncertainties about how to best assess and minimize impacts to California's bird and bat populations would expedite repowering of existing sites and development of new wind resource areas. The *Guidelines* have helped to establish consistent methods for assessing bird and bat impacts, but information gaps remain on some of the recommended methodology. PIER can help close these information gaps by collaborating with ongoing research efforts and by conducting its own targeted research. PIER will work with state and federal agencies, non-governmental organizations, research collaboratives, and wind energy developers to leverage research funds, draw upon previous and ongoing efforts, and ensure the applicability of the research.

Chapter 4: Research Needs

This chapter identifies priority research issues that need resolution to improve methods to assess and mitigate impacts to birds and bats from wind energy development in California. Two overarching questions encompass this needed research:

1. What information is needed to establish a better linkage between pre-permitting data on bird/bat use and site characteristics with bird/bat fatalities during turbine operation?
2. What scientifically supportable methods are available to avoid, minimize, and mitigate bird and bat fatalities?

Addressing the following research needs will fine-tune survey techniques and increase the predictive power and usefulness of pre-permitting surveys at wind resource areas in California. The ultimate goal is to more accurately forecast and mitigate the impacts of new projects and repowering projects on avian and bat species

Bird Survey Techniques

The methods for measuring diurnal bird use and abundance at proposed project sites are relatively standardized and consistent, but questions remain as to how well the pre-permitting observational data on abundance and behavior predict bird fatalities during operation, and how variations in study design, metrics, and techniques might affect the assessment of risk. Research is needed to resolve remaining questions on the most useful and cost-effective techniques for assessing diurnal bird use and abundance and risk of collision. A related research question is how pre-permitting bird use and fatality data compare among studies from various facilities in California, and how these comparative data can be used to improve the micro-and macro-siting of future wind energy facilities. We need a better understanding of which patterns of use and behavior detected with pre-permitting studies are consistent among various regions in California, what variation in fatalities is explained by new versus old turbine technology, and how differences in species, habitat types, topography, and other regional characteristics affect fatalities. The ultimate goal is to identify regional site characteristics (topography, weather, bird species composition and abundance) that are correlates of high or low risk, possibly creating a map-based indicator of collision risk.

Research Needs:

- **Assess Effect of Variations in Diurnal Bird Survey Techniques on Accuracy of Risk Estimation.** Assess existing pre-permitting data and monitoring results from wind energy projects in California and elsewhere to determine how variations in pre-permitting study design, survey techniques, and survey duration affect pre-permitting estimates of relative abundance and risk for diurnal birds. Determine which techniques are consistently the most cost-effective and useful for estimating collision risk throughout the state's wind resource areas.
- **Develop Bird Fatality Estimates for California Wind Resource Areas and Identify Correlates of Risk.** A long-term research need is to conduct a meta-analysis of pre-

permitting and operations fatality data from wind energy developments that used methodology recommended in the *Guidelines*. This relatively consistent data set can be used to develop a range of fatality estimates for birds at wind resource areas throughout California, focusing on wind resource areas that will experience significant expansion and/or repowering. This analysis should include an assessment of how variables measured during pre-permitting studies correlate with monitored bird fatality rates throughout the state.

Species-Specific Vulnerability to Collisions and Population Impacts

California bird and bat species vary in their vulnerability to collisions with wind turbines because of their inherent characteristics and behavior. More research is needed to characterize behavioral avoidance of species/species groups at California wind resource areas at a representative array of turbines and habitats, and to assess which pre-permitting data collection techniques best capture the behavior that puts species at collision risk.

California's bird and bat species also vary in their vulnerability to population-level impacts as a result of fatalities from wind energy development combined with impacts from other sources. Widespread and abundant species are unlikely to experience significant impacts at a population level as a result of wind development, but for some species even a relatively minor increase in mortality could have significant impacts. To avoid the potential risk of population-level impacts, California's species of special concern should be assessed and prioritized to determine which might be potentially threatened by wind energy development. Depending on the results of this assessment, a long-term research goal may need to include field and lab studies and Population Viability Analysis directed at species deemed to be at risk of significant cumulative population declines from wind energy development.

Research Needs:

- **Evaluate Behavioral Differences Between Species/Species Groups That Affect Collision Risk.** Analyze existing data sets to determine which California bird and bat species or species groups (for example, raptors, tree-roosting migratory bats) are consistently prone to collisions, and the behavioral correlates of that risk. Conduct field studies to verify hypotheses about consistent patterns of risky behavior for species or species groups.
- **Identify Species at Risk of Population-Level Effects of Wind Energy Development on Birds and Bats.** Identify which special-status bird and bat species in California might experience significant population declines from wind energy development. Using monitoring reports and the published literature, evaluate the known fatality factors and rates for species potentially at risk of population-level declines, and assess the potential added influence of increased fatalities from wind energy development. The focus of this research should be to identify locally rare populations as well as overall rare species.

- **Evaluate Demographics/Population Level Impacts** A long term research need might include field studies of those species/species groups deemed to be at risk of cumulative population declines. Analyses of feathers or carcasses could be used to determine age and geographic origin of individuals most susceptible to collisions. Insights from this research might help elucidate patterns of fatality, most susceptible groups of individuals, and whether populations of birds or bats killed are of local origin or not. These data would be necessary to properly model population-level impacts.

Habitat, Species, and Resource Development Land-Use Mapping

The National Research Council (NRC 2007), the Wildlife Society (Arnett et al. 2007), and many participants in the *Guidelines* (CEC and CDFG 2007) development process described the need for habitat/species maps that could inform the appropriate siting of new wind resource areas. These maps would offer information about the location, magnitude, and timing of bat and bird movements during spring and fall migration, and depict the areas occupied by species of special concern during the breeding and nonbreeding seasons. Ideally these maps would identify (1) locations where potential wind resource areas might overlap with critical habitat, ecologically important intact landscapes, or habitat critical to the maintenance of special-status-species populations; and (2) synthesize local and small-scale impacts to identify possible large-scale impacts. Such maps would allow comparison of multiple sites when making decisions about siting new wind energy developments.

Ultimately such maps might be used to assess potential land-use and conservation conflicts extending beyond wind energy development, and could provide a tool to conduct regional assessments and forecasting of cumulative land-use impacts from many kinds of energy development. Given projected increases in the development of California's solar, wind, biomass, and oil and gas resources, conflicts surrounding land-use, mitigation, and conservation strategies will be inevitable and are already occurring. The Wildlife Society (Arnett et al. 2007) points out that regional assessments of existing land use and multiple forecasts of possible land uses are needed, and planning regional conservation strategies among industries, agencies, and private landowners could reduce conflicts and increase options for mitigation and conservation.

Resource-mapping of species and habitats combined with comprehensive regional planning will be essential if California's renewable and nonrenewable energy resources are to be developed without far-reaching impacts on the state's wildlife populations. Creating resource/species maps with the detail needed to be useful for wind resource area siting decisions will require a long-term level of effort and funding beyond that envisioned in this Roadmap, as well as a process to address the interests of multiple agencies and the public. This long-term research effort is described below.

Research Needs

- **Develop Species/Habitat Maps for California Wind Resource Areas.** Compile database/maps that would provide the following information for California's wind

resource areas: the location, magnitude, and timing of movements of California bats and birds during spring and fall migration; areas occupied by species of special concern during the breeding and nonbreeding seasons; and ecologically important/sensitive habitats. The maps should be accessible to wind energy developers, resource agencies, decision makers, and the public, and provided in a form that allows the maps to be overlaid with regional land-use and conservation plans.

Effects of Turbine Design and Site Characteristics on Fatalities

Wind turbine design, the layout of wind turbines, and the surrounding topography have been hypothesized as contributing, singly or together, to increased risk of bird and bat collisions. The new-generation wind turbines differ substantially from their predecessors in terms of turbine and blade dimensions, blade rotation speed, and spacing of turbines, and may also differ in their potential impacts to birds and bats. The repowering now occurring throughout California provides an opportunity to assess how the new turbine designs affect fatality rates for different species.

Variations in topography relative to turbine placement have also been proposed as factors influencing collision risk, and micro-siting of turbines has been recommended as a means to minimize collision risk. However, the interplay of turbine design, habitat characteristics, and behavioral differences among species at wind resource areas confounds the results, and different factors appear to be important under different environmental conditions. Relying mostly on data from old-generation turbines, researchers have concluded that the location of turbines relative to each other or to topographic features of the site can affect risk of collision, and that careful siting of wind turbines (avoiding turbines near edges of canyons) can reduce fatalities. More information is needed to assess whether these observations are also applicable to new-generation turbines, and if any other micro-siting recommendations can be extracted from an analysis of data from new turbines.

Research Needs:

- **Assess Effects of Repowering on Birds and Bats.** Analyze pre-permitting and operations data collected from new and old turbines at wind resource areas that have data sets from both turbine types to better understand how repowering affects fatality rates of bat and bird species.
- **Evaluate Effect of Turbine Micro-siting on Fatality Rates.** Using information from wind resource areas with new-generation turbines, conduct a meta-analysis of fatality data in relation to turbine configuration/topography. Determine if consistent patterns exist that could be applicable to micro-siting decisions at wind resource areas in California.

Nocturnal Survey Techniques and Correlates of Risks for Bats/Birds

Considerable variation and uncertainty exist among the diverse methods to evaluate the species composition, relative abundance, flight height, and trajectory of bats and nocturnal birds, and how to apply this information to estimating collision risk. Marine radar can determine passage rates, flight heights, and flight directions of nocturnally active animals, but its data have not yet been demonstrated to be a reliable indicator of collision risk. Nocturnal imaging techniques such as thermal imaging similarly have no successful track record in estimating collisions, although they are helpful in distinguishing birds, bats, and insects during radar studies. Acoustic detectors are the most frequently used tool to study bat activity at a site, and thermal infrared imaging and mobile radar units are two additional techniques that can be employed to identify which animals are present at a site and to identify their flight path (Kunz et al. 2007a). Existing Doppler weather surveillance radar systems have collected a huge data set containing information on the movements and use patterns of nocturnal birds and bats, but this source is useful only to those few biologists with the technical skills to decipher the obscure data formats and extract biologically meaningful results (Ruth et al. 2005).

Each of these tools has its strengths, limitations, and uncertainties; field research and analysis of existing data are needed to determine how to best deploy these devices, and how the data generated from different techniques can be used in a cost-effective, complementary fashion. A high-priority research need is, therefore, to field-test pre-permitting survey techniques that will provide an index of bat activity, and then determine if that index provides a reliable estimate of bat fatalities during wind turbine operation. A long-term research need is to compile and analyze the bat data from pre-permitting and operations studies with the ultimate goal of discerning regional patterns in activity and fatalities and correlates of risk.

Research Needs:

- **Assess Nocturnal Survey Techniques for Estimating Activity.** Determine what combination of sensing techniques (such as acoustic sampling, mobile radar units, Doppler radar, thermal infrared imaging, dawn and dusk surveys) provide the most reliable data set on the occurrence of bats and nocturnal birds and which will ultimately be useful and cost-effective in estimating collision risk. Examine existing data from Doppler radar stations within and near California to look for consistent patterns of movements that might be useful in predicting risk to nocturnal birds and bats.
- **Assess the Predictive Value of Bat Survey Techniques in Estimating Bat Fatalities During Operations.** Determine if indices of pre-permitting bat activity can successfully predict bat fatalities at proposed wind energy facilities in California. The goal of this research would be to determine the level and patterns of activity of different species groups of bats using the proposed wind facility prior to turbine construction, to correlate bat activity with weather and other environmental variables, to compare the pre-permitting data to operations fatality data, and to use this information to develop the most cost-effective methods for assessing and mitigating impacts to bats. PIER is currently supporting this kind of research at a wind facility near Palm Springs in Southern California; similar studies are needed at wind resource areas throughout the state.

- **Develop Bat Fatality Estimates at California Wind Resource Areas and Identify Correlates of Risk.** A long-term research need is to conduct a meta-analysis of bat data from pre-permitting and operations fatality studies at wind energy developments throughout the state. California currently has only a meager data set on bat activity levels and fatality rates, but after a relatively consistent data set is collected over the next five to ten years, this information can be used to develop fatality estimates for bats at wind resource areas throughout California, focusing on regions that will experience significant expansion and/or repowering. This analysis should include an assessment of how variables measured during pre-permitting studies correlate with fatality rates at operating wind developments throughout the state.

Post-Construction Fatality Monitoring

An accurate accounting of bird and bat fatalities during turbine operation is the most crucial component in (1) determining if pre-permitting surveys were correct in assessing which elements of a site or bird/bat behavior might be classified as “risky” and (2) evaluating permit compliance and the effectiveness of mitigation measures. Opportunities for inaccuracies creep in at every stage of fatality monitoring, from the development of study design (size of the carcass search area, frequency of searching), to the execution of the study (searcher training, frequency and protocol for searcher efficiency, surrogates used for scavenging trials), to the analysis (which equation to use to correct for biases). More research is needed on the basic elements of carcass search protocols to reduce some of the uncertainties and inaccuracies associated with current fatality monitoring techniques. In addition, a number of equations are found in monitoring reports and the peer-reviewed literature for adjusting the measured fatality rate to better reflect the true number of birds and bats killed by collisions with wind turbines. Statisticians knowledgeable about the application of these equations differ as to whether various equations over- or underestimate true fatalities. When these issues are resolved, the larger questions about linking fatality data with abundance and use data can be addressed. Many of the questions about fatality monitoring methods are amenable to experimental field trials because many of the variables (such as size of search area, study design, type and deployment of surrogate carcasses, search interval) can be manipulated by the researcher.

Research Needs:

- **Assess How Variations in Search Area and Search Frequency Affect Accuracy of Carcass Counts.** Conduct daily carcass searches at wind facilities and conduct simulations with the resulting data to determine the search frequency that provides an acceptably accurate, cost-effective carcass count. Analyze field study results in the context of fatality data from existing wind resource areas to determine the search area and interval that provides the most cost-effective, accurate carcass count.
- **Evaluate How Variation in Scavenging Trials Affects Accuracy of Carcass Counts.** Undertake experimental field studies to determine how accurately scavenging trials reflect actual carcass removal. The field studies should assess how the deployment and

characteristics of the surrogate carcasses affect the detectability and appeal of carcasses to scavengers and searchers, if scavenger removal rates can be consistently predicted by body size or taxa, and if fatality monitoring can be designed to account for the ability of vertebrate scavengers to learn foraging routes at wind resource areas.

- **Evaluate Fatality Adjustment Equations Used to Correct Biases from Scavenging and Searcher Error.** Assess the inherent biases of the formulae that have been used to correct for searcher error, scavenging, and other sources of bias. Recommend methods to accurately account for searcher detection error and scavenger removal of carcasses in the estimates of fatalities. Test mathematical approaches for estimating the true fatalities under conditions in which the true mortality is known, and assess methods for estimating the error in the resulting estimates.

Bat Auditory Deterrents and Operations Modification

No alerting or deterring mechanisms have yet been shown to be effective in reducing bat fatalities at wind turbines, but the Bats and Wind Energy Cooperative is currently working to test such mechanisms using high-intensity ultrasound to prevent bat collisions with rotors. Thus far the laboratory studies show some promise; systematic field testing is needed, however, and any feasible deterrent must overcome the obstacle of rapid attenuation of high-frequency sound in a field setting.

Another post-construction method of minimizing bat impacts is to adopt relatively minor operations modifications during the periods of highest risk. The evidence thus far suggests that most bat fatalities occur during fall migration on nights when winds are low (Weller 2008; Kunz et al. 2007). Curtailing operations or changing “cut-in” speeds at these times might be effective in reducing bat fatalities with relatively small impact on power production. Kunz et al. (2007) have proposed evaluation of various curtailment treatments at existing wind resource areas. Any analysis of curtailment should be accompanied by an economic analysis of the costs of decreased power production and possible penalties.

Research Needs:

- **Conduct Studies on the Effectiveness of Bat Deterrents.** Collaborate with other researchers in lab and field studies of auditory deterrents (high-intensity ultrasound) to assess their effectiveness in reducing collision risk for bats at wind resource areas in California.
- **Assess Effectiveness of Operations Modifications on Bat Behavior and Fatalities.** Work with other researchers on field studies assessing changes in bat fatalities as a result of shutdown or “feathering” of wind turbine blades and changes to “cut-in” speed. These experiments would be conducted on low-wind nights when power production is relatively low, and could include an observational component using thermal infrared imaging as well as a carcass count to determine if the feathering or curtailment reduces fatalities.

Buffer Zones for Birds and Bats

Protective buffer zones around raptor nests, bat roosts, and sensitive habitats/high-wildlife-use areas are routinely recommended as mitigation measures for wind energy projects. However, few studies have been conducted to determine the proper design of such buffers—or if they are even effective. Research is needed to determine whether buffer zones can reduce impacts of wind energy development to birds and bats, to identify species and habitats for which buffer zones would provide protection, and the necessary size of the buffer zone.

Research Need:

- **Evaluate the effectiveness of buffer zones in reducing impacts to birds and bats.** Identify habitat-specific and species-specific buffer zone mitigation strategies that have been employed at operating wind energy projects, and assess the effectiveness of these buffers in avoiding direct and indirect impacts. Review and compile information from the scientific literature for species in California that have been considered sensitive and recommended for buffering. For potentially sensitive species, conduct post-construction monitoring at existing wind sites to see if birds or bats are displaced and to what degree.

Assess Effectiveness of Compensatory Mitigation

Compensatory mitigation is used to offset fatalities and other unavoidable impacts of wind energy development on birds and bats, and is an increasingly common element of permit conditions. A long-term research need is to evaluate the effectiveness of compensatory mitigation required for offsetting impacts to impacted species, and to look for opportunities to improve the benefits of such mitigation.

Research Need:

- **Assess Effectiveness of Compensatory Mitigation Approaches.** Identify wind energy projects that have included compensatory mitigation and compile information about the effectiveness of that mitigation in achieving the stated objectives. Evaluate the nexus between the fatalities occurring during operation of the wind turbines and the benefits to affected species provided by habitat acquisition and enhancement. Recommend better ways to implement compensatory mitigation and more closely link the impact of wind energy development with the mitigation proposed to offset that impact.

CHAPTER 5: Goals

The primary goal of PIER's wind energy-wildlife research is to increase certainty in methods and metrics used to assess and mitigate impacts to birds and bats from wind energy developments in California. This chapter lists short- and long-term research objectives, describing the activities needed to (1) improve the methods used to identify and avoid impacts, (2) better understand fatality patterns, and (3) reduce these fatalities and offset impacts of wind energy development. The PIER Program recognizes that some work is currently under way in these areas and seeks to draw from, build upon, and broaden the focus of those efforts. PIER encourages collaboration with existing efforts and the formation of partnerships to leverage resources.

Critical factors for success are listed below each specific objective, but several of these factors are common to some or all of the research goals. These include:

- **Access to Raw/Summary Data.** Some pre-permitting data from wind resource areas is proprietary information that has never been published or provided to a public agency. PIER and researchers will need to work collaboratively with wind industry representatives to ensure appropriate data analysis and confidentiality.
- **Screening Criteria for Gray Literature.** For research that relies on analyses of existing reports and published articles rather than experimental field studies, information that comes from the "gray" literature (monitoring reports, summaries and transcripts of presentations, other reports outside of peer-reviewed publications) will require careful screening to evaluate quality and relevance. Screening will ensure that only well-designed studies with adequate sample sizes and sound statistical or qualitative analyses are used as a basis for conclusions. Ideally the research used for meta-analyses and literature reviews will be based on experimental or controlled studies, but research relying on descriptive or comparative studies can also be useful if weaknesses in the design or analysis of the studies are adequately identified and discussed.
- **Establish Clearinghouse to Host and Share Data.** Pre-permitting data and other gray literature used for some of the research analyses described below will need to be available to interested parties so that other investigators can review and verify use of that information. While PIER cannot provide such a clearinghouse, a resource agency or non-governmental organization might be able to host and share these data (for example, California Department of Fish and Game's Biogeographic Information and Observation System (BIOS), U.S. Fish and Wildlife Service, or the American Wind Wildlife Institute).
- **Access to Wind Resource Areas for Field Studies.** Some wind energy resources have been developed on public lands such as the Bureau of Land Management, but many proposed and existing wind resource areas are on private property leased explicitly for wind development. While the terms of the lease provide access for maintenance workers and other representatives of the wind energy developer, they generally do not include permission for researchers to enter the property. PIER and researchers will need to work

collaboratively with wind industry representatives and landowners to ensure investigators have access to wind resource areas for the duration of the field studies.

- **Statistically Sound Study Design.** Where field studies are recommended to resolve areas of uncertainty, the researcher needs to evaluate, select, and implement a sound study design so that the results are replicable and statistically valid. Anderson (1999), Morrison et al. (2001), Morrison et al. (2007), Erickson et al. (2007), and Strickland et al. (2007) provide good descriptions of study designs relevant to the kinds of research discussed below.
- **Publication in Peer-Reviewed Journals.** For some of the research issues discussed below, there is currently little consensus among experts. For these topics, research results must be published in peer-reviewed journals to receive acceptance from the scientific community and other parties.
- **Dissemination of Results to Decision-Makers/Public.** Results from the research described below must be published in a fashion that makes them accessible to a wider audience than just wind-wildlife researchers. California counties, cities, and utilities that permit wind energy projects need this information, as do resource agencies such as the California Department of Fish and Game and the U.S. Fish and Wildlife Service. In addition to a technical report of research findings, significant results should also be provided in a form useful and accessible to decision makers and the public.

Short-Term Objectives³

Assess Effect of Variations in Diurnal Bird Survey Techniques on Fatality Estimates

Activities needed:

1. Secure pre-permitting and operations monitoring data (raw and summary data) from existing wind energy projects in the state. Assess the precision and accuracy of specific metrics from these data (for example, fatalities, abundance, bird occurrence in rotor-swept area) as a function of data collection protocols, sample sizes, sample placement strategies, and monitoring durations.
2. Conduct a new, in-depth analysis of the data and/or simulations to assess how variations in data collection protocols (for example, frequency, duration, and radii of point counts/visual scans) and other survey methods affect estimates of bird use and risk.

3. *Short-term* refers to a 1–3 year time frame and *long-term* to 3–10 years. The activities specified in this Roadmap are projected to begin sometime within the designated time frames; the duration of actual projects may be less than the entire term specified.

Critical factors for success:

- Access to raw/summary data
- Screening criteria for gray literature
- Established clearinghouse to host and share data
- Statistically sound study design
- Publication and dissemination of results

Evaluate Behavioral Differences between Species/Species Groups That Affect Collision Risk

Activities needed:

1. Analyze existing data sets to determine which California bird and bat species or species groups (for example, raptors, tree-roosting migratory bats) are consistently prone to collisions, and the behavioral correlates of that risk for representative arrays of turbines and habitats.
2. Conduct field studies (for example, thermal imaging of bats in the vicinity of wind turbines, observations of diurnal birds within the rotor-swept area of operating wind turbines), to verify hypotheses about patterns of consistently risky behavior for species or species groups.

Critical factors for success:

- Access to raw/summary data
- Screening criteria for gray literature
- Established clearinghouse to host and share data
- Statistically sound study design
- Access to wind resource areas
- Publication and dissemination of results

Assess Potential Population-Level Effects of Wind Energy Development on Birds and Bats

Activities needed:

1. Identify which special-status bird and bat species in California for which wind energy development may contribute to significant population declines based on existing literature (for example, Shuford and Gardali 2008; California Bat Working Group 2006).
2. Using monitoring reports and the published literature, quantify the known mortality factors and rates for those species. Estimate the annual mortality from all sources, natural and anthropogenic.
3. Develop a list of species in California potentially at risk of population decline from wind energy development.
4. Determine if additional analyses and field studies are warranted to evaluate the effect of wind energy development on declining populations.

Critical factors for success:

- Access to raw/summary data
- Screening criteria for gray literature
- Established clearinghouse to host and share data
- Publication and dissemination of results
- Adequate database to run models

Assess Effects of Repowering on Bird and Bat Fatalities

Activities needed:

1. Secure pre-permitting and operations monitoring data from new and old turbines at wind resource areas that have data sets from both (for example, Collinsville Montezuma Hills Wind Resource Area in Solano County and Altamont Pass Wind Resource Area in Alameda County).
2. Analyze these data to determine which California species are prone to collisions based on turbine characteristics and other factors (behavior, habitat, season) that might interact to increase exposure to collision at new versus old turbines.

Critical factors for success:

- Access to raw/summary data
- Screening criteria for gray literature

Established clearinghouse to host and share data

- Publication and dissemination of results.
- Adequate use and fatality data from old turbines

Evaluate Effect of Turbine Micro-Siting on Bird and Bat Fatality Rates

Activities needed:

1. Compile information on bird and bat fatality rates from wind resource areas with new-generation turbines.
2. Analyze the changes in fatality rates of birds and bats in relation to turbine configuration/topography.
3. Determine if consistent patterns exist that could be applicable to micro-siting decisions at wind resource areas in California.

Critical factors for success:

- Access to raw/summary data
- Screening criteria for gray literature
- Established clearinghouse to host and share data
- Publication and dissemination of results

Assess Nocturnal Survey Techniques and Correlates of Collision Risk

Activities needed:

1. Determine which sensing techniques (such as acoustic sampling, mobile radar units, Doppler radar, thermal infrared imaging, dawn and dusk surveys) provide the most reliable data set on occurrence of nocturnal birds and bats and which will ultimately be useful and cost-effective in estimating collision risk.
2. Examine existing data from Doppler radar stations within and near California to look for consistent patterns on movements of nocturnal migrants that might be useful in predicting risk to bird and bat populations.
3. Continue ongoing PIER bat–wind turbine research to assess how well data on bat activity levels before construction correlate with bat fatalities during turbine operation.
4. Expand these study efforts to new sites at Tehachapi, Mojave, and other areas where wind development is proposed.

Critical factors for success:

- Access to raw/summary data
- Availability of radar data for wind resource areas
- Screening criteria for gray literature
- Established clearinghouse to host and share data
- Statistically sound study design
- Access to wind resource areas
- Publication and dissemination of results

Assess How Variations in Search Area and Search Frequency Affect Accuracy of Carcass Counts

Activities Needed:

1. Undertake field studies at existing wind facilities to determine how variations in search area and frequency affect the accuracy of carcass counts.
2. Conduct simulations with the resulting data to determine the search frequency that provides an acceptably accurate, cost-effective carcass count.
3. Analyze results from the field studies and simulations in the context of fatality data from existing wind resource areas to determine the search area and interval that provide the most cost-effective, accurate carcass count.

Critical factors for success:

- Access to raw/summary data
- Screening criteria for gray literature review
- Established clearinghouse to host and share data
- Statistically sound study design
- Access to wind resource areas
- Publication and dissemination of results

Evaluate How Variation in Scavenging Trials Affects Accuracy of Carcass Counts

Activities Needed:

1. Conduct experimental scavenging trials in the field to determine how the accuracy of carcass counts varies depending on carcass characteristics (size, domestic/nonnative versus wild/native, frozen versus fresh, whole versus wounded) and deployment (putting out many carcasses at once versus putting out a few).
2. Analyze the data to assess how the characteristics and deployment of surrogate carcasses affect their detectability and appeal to scavengers and searchers, and if scavenger removal rates can be consistently predicted by body size or taxa.

Critical factors for success:

- Availability of carcasses for field trials
- Access to raw/summary data
- Screening criteria for gray literature
- Established clearinghouse to host and share data
- Statistically sound study design
- Access to wind resource areas
- Publication and dissemination of results

Evaluate Fatality Adjustment Equations Used to Correct Biases From Scavenging and Searcher Error

Activities needed:

1. Assemble a panel of statisticians to review the existing equations used to correct for sources of error in carcass count data, and identify potential sources of error that could be tested with mathematical simulations and field trials.
2. Field-test mathematical approaches for estimating fatalities under conditions in which the true mortality is known, and assess methods for estimating the error in the resulting estimates.

Critical factors for success:

- Developing consensus among all parties as to the appropriate composition of a panel of statisticians to review existing formulas and identify the inherent assumptions and sources of errors
- Statistically sound study design
- Access to wind resource areas
- Publication and dissemination of results

Investigate Effectiveness of Auditory Bat Deterrents

Activities needed:

1. Collaborate with ongoing laboratory and field studies of auditory deterrents (high-intensity ultrasound) to assess their effectiveness in reducing collision risk for bats at California wind resource areas.

Critical factors for success:

- Collaboration with ongoing research
- Statistically sound study design
- Publication and dissemination of results
- Address feasibility/cost-effectiveness of this technique for widespread use under field conditions.

Assess Effectiveness of Operations Modifications on Bat Behavior and Fatalities

Activities needed:

Conduct experimental field studies at operating wind resource areas to assess the mitigation potential of shutdown, “feathering” of wind turbine blades, and/or changing cut-in speed on low-wind nights when power production is relatively low and collision risk to bats is high.

Critical factors for success:

- Collaboration with ongoing research
- Access to wind resource areas
- Collaboration with wind turbine operators to address loss of power production and income associated with feathering experiments
- Statistically sound study design
- Publication and dissemination of results

Evaluate Effectiveness of Buffer Zones in Reducing Impacts to Birds and Bats

Activities needed:

1. Identify habitat-specific and species-specific buffer zone mitigation strategies that have been employed at operating wind energy projects, and assess the effectiveness of these buffers in avoiding direct and indirect impacts to birds and bats.
2. Review and compile information from the scientific literature for species in California that have been considered sensitive and recommended for buffering.
3. For sensitive species determined to potentially benefit from buffering, conduct field investigations using a Before-After/Control Impact study design to assess the effectiveness of buffer zones for those species.

Critical factors for success:

- Access to raw/summary data
- Screening criteria for gray literature
- Established clearinghouse to host and share data
- Access to wind resource areas
- Statistically sound study design
- Publication and dissemination of results

Long-Term Objectives

In the decades to come, researchers will have a much improved data set and tools with which to analyze long-term trends and patterns of impacts to birds and bats at California's wind resource areas. Consistent application of the methods recommended in the *Guidelines* will eventually produce comparable statewide data that can be used to more accurately estimate impacts to birds and bats from wind energy development, and to successfully avoid or mitigate those impacts. In addition, PIER's short-term research efforts and those of other investigators throughout the country will resolve many of the uncertainties that currently undermine our ability to accurately assess impacts and successfully mitigate them. With a consistent California data set on wind-wildlife interactions, and the results of the research goals described above, the following long-term goals can be addressed.

Develop Bird and Bat Fatality Estimates at California Wind Resource Areas and Determine Pre-Permitting Correlates of Risk

Activities needed:

1. Secure pre-permitting and operations monitoring data (raw and summary data) from wind energy projects that used the methods recommended in the *Guidelines*.
2. Conduct a meta-analysis of pre-permitting and operations fatality data to develop fatality estimates for birds and bats for wind resource areas throughout California, focusing on wind resource areas that will experience significant expansion and/or repowering. This analysis should include an assessment of how variables measured during pre-permitting studies correlate with monitored bird fatality rates throughout the state.

Develop Species/Habitat Maps for California Wind Resource Areas

Activities Needed:

1. Compile a database and create maps that would provide the following information for California's wind resource areas: the location, magnitude, and timing of movements of California bats and birds during spring and fall migration; areas occupied by species of special concern during the breeding and nonbreeding seasons; fatality rates of birds and bats at existing wind resource areas; and ecologically important/sensitive habitats.
2. Develop an interactive atlas or portal that allows the user to explore these data layers in relation to wind resources and land use.

Conduct Studies to Assess Cumulative Population Impacts

Activities Needed:

1. For species deemed to be at risk of significant population declines, conduct lab analyses of feathers or carcasses to determine age and geographic origin of individuals killed at wind turbines.
2. Evaluate patterns of mortality, identify most susceptible groups of individuals, and determine whether populations of birds or bats killed are of local origin or not.
3. Conduct Population Viability Analyses for species in California that may be at risk of cumulative population impacts.

Assess Effectiveness of Compensatory Mitigation Approaches

Activities needed:

1. Identify wind energy projects that have included compensatory mitigation and compile information about the effectiveness of that mitigation in achieving the stated objectives. Evaluate the nexus between the fatalities occurring during turbine operation and the benefits to impacted species provided by habitat acquisition and enhancement.
2. Recommend improvements on developing and implementing compensatory mitigation measures, and research ways of more closely linking the impact of wind energy development with the mitigation proposed to offset that impact.

CHAPTER 6: Leveraging R&D Investments

Some of the research recommended in this Roadmap is being planned or is currently being conducted in one form or another by organizations such as the Bats and Wind Energy Cooperative (BWEC), U.S. Department of Energy, National Renewable Energy Laboratory, Lawrence Livermore National Laboratory, National Wind Coordinating Collaborative (NWCC), American Wind Wildlife Institute, Altamont Pass Wind Resource Area's Scientific Review Committee, New York State Energy Research and Development Authority, Point Reyes Bird Observatory Conservation Science, and others. In addition to these agencies and non-governmental organizations, during the *Guidelines* development process many wind industry representatives (for example, PPM Energy, Horizon, FPL Energy) expressed an interest in working together with researchers to further the goals described here.

PIER intends to maintain and strengthen existing collaborative relationships with these public and private entities, and to develop new ones as needed. PIER's collaboration with other research organizations and industry will foster complementary use of resources, enhance problem solving, and increase the level of funding available to tackle specific research issues. Working together on mutual research goals also provides increased opportunities for peer reviews and dissemination of preliminary and final research results. PIER will actively pursue opportunities to leverage funds to fulfill the research objectives described here, including prioritizing projects which offer matching funding. Revised priorities may be necessary if new results from ongoing research at other institutions resolve some of the uncertainties and information gaps described in this Roadmap.

PIER will continue to work in collaborative forums such as the NWCC Wildlife Workgroup on these common research interests, but also plans to actively partner with groups as needed to achieve research objectives. For example, PIER's investigation of sampling regimes to characterize bat activity at a Southern California wind energy project (Weller 2007) involved collaboration with BWEC and PPM energy. PIER will continue to pursue that kind of cooperative research effort, particularly with respect to bat-wind turbine interactions, because this is currently an area of intense research focus and PIER's participation would accelerate achieving some of the stated research objectives.

Cooperative relationships with California's wind energy developers are not just desirable but essential to achieve many of the research goals described in this Roadmap. Some of the research requires access to information held by wind industry, and to private property they lease for their facilities. While PIER funding cannot be used to assist in fulfilling project-specific permit conditions or environmental compliance efforts, such collaborations will indirectly benefit wind industry by providing useful information that can be applied to specific projects.

Chapter 7: Areas Not Addressed by This Roadmap

Interest in research about wildlife–wind turbine interactions has expanded in the past decade, and several publications address current research priorities in this field. One of the most recent assessments of research priorities is the *Wind and Wildlife Key Research Areas*, a publication prepared by the National Wind Coordinating Collaborative (NWCC) Wildlife Workgroup (NWCC 2007). This document compiled researched needs identified by The Wildlife Society (Arnett et al. 2007) and the National Academy of Sciences (NRC 2007), as well as surveys among members of the NWCC and other organizations such as the California Energy Commission and the New York State Energy Research and Development Authority. In addition to these compilations of research priorities, Warren-Hicks and Newman (2008) developed a critique of the scientific basis for the recommendations in the *Guidelines* (CEC and CDFG 2007) and suggested research to resolve some of the uncertainties associated with the methods and assumptions underlying the recommendations. Many of the suggestions for research from these sources are reflected in the preceding chapters of this Roadmap, but some topics identified as important priorities are not addressed in this document. This chapter discusses some of the issues not addressed in the Roadmap and the reasons they were omitted.

Comparative Generation Technology Alternatives Analysis

Wind energy indirectly benefits wildlife by displacing electricity generation from fossil fuel sources, therefore reducing the adverse effects on air quality and climate. To fully evaluate these benefits, an analysis would be needed to assess the environmental effects of generating electricity from other energy sources, and to compare them all to the adverse effects of wind energy. While such an analysis would produce useful information for decision makers to weigh the adverse impacts of a wind energy project against its environmental benefits, it is beyond the scope of this Roadmap. The purpose of the Roadmap is to guide research that will strengthen the specific methods used to assess and mitigate the impacts of wind turbines on birds and bats.

Impacts to Habitat

This Roadmap does not directly address habitat-related impacts to wildlife (habitat loss, fragmentation) associated with the construction of wind energy facilities. The environmental impact of constructing wind turbines and associated infrastructure such as roads is a common element of any wind development project in California and is already adequately addressed by existing state and federal laws. See Arnett et al. (2007) for a discussion of impacts to wildlife from habitat loss and fragmentation from construction of wind energy facilities.

Impact of Small-Scale Turbines

This Roadmap does not explicitly address the direct/indirect impacts to birds and bats from the construction and operation of wind-powered electric systems sized for homes, farms, and small businesses (100 kilowatts in capacity and below).

Offshore Wind Energy Development

Impacts to birds and bats from offshore wind energy facilities are excluded from this report because there currently are no such installations in California or elsewhere in North America (NRC 2007). With relatively few offshore sites developed worldwide, little information has been collected regarding the risk to wildlife of offshore wind farms. Kingsley and Wittam (2005) describe some basic questions that need to be answered regarding the wildlife impacts of offshore wind turbines. Future Roadmaps may need to address research needs associated with development of California's offshore wind resources. According to an initial analysis performed by Stanford University, theoretically at least 25 percent of California's electricity needs could be supplied by offshore wind turbines (Dvorak et al. 2007).

Collision Sensors

This Roadmap does not discuss ongoing research to develop sensor devices that would provide an automated tool to monitor bat/bird collisions with wind turbines. PIER has supported studies of automated monitors to gather information on bird strikes at transmission lines and wind turbines (EPRI 2003). Other PIER studies on this topic include Pandey et al. (2007) which is a report on the initial phase of a three-phase effort to develop an automated bird/bat collision monitor that is reliable, affordable, and does not significantly impair wind turbine performance.

Decision Frameworks

Warren-Hicks and Newman (2008) recommended research to develop a decision-oriented framework such as ecological risk assessment as an alternative to the categories described in the *Guidelines* (CEC and CDFG 2007). They note that the NWCC (2007a) suggests a decision-oriented, tiered paradigm may help determine impacts to birds and bats at wind turbine facilities, and such processes are used by agencies around the world. They recommend research involving a comprehensive literature review, evaluation of existing decision frameworks for wind turbine assessments and selection of most workable frameworks, then on-site evaluation and testing of selected decision frameworks.

Decision frameworks were discussed during the *Guidelines* development process and will be discussed again with opportunities for public input when the *Guidelines* are revised. The research recommended to assess existing frameworks would be an appropriate activity as part of the revision process. A field evaluation of a selected decision framework may be an appropriate subject of future PIER research. The goal of this Roadmap, however, is to guide research efforts that will strengthen the specific methods used to assess and mitigate the impacts of wind turbines on birds and bats.

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CHAPTER 9: Glossary

List of Acronyms

APWRA	Altamont Pass Wind Resource Area
AWI	Altamont Wind Incorporated
BWEC	Bats and Wind Energy Cooperative
BIOS	Biogeographic Information and Observation System
CBWG	California Bat Working Group
CDFG	California Department of Fish and Game
CEC	California Energy Commission
FAA	Federal Aviation Administration
ISO	Independent System Operator
MW	Megawatt
NEXRAD	Next-generation radar
NRC	National Research Council
NWCC	National Wind Coordinating Committee
PIER	Public Interest Energy Research
PVA	Population viability analysis
RD&D	Research, development, and demonstration
RPS	Renewable portfolio standard
USFWS	U.S. Fish and Wildlife Service
WRA	Wind resource area

Definition of Terms

Accuracy: The agreement between a measurement and the true or correct value.

Avian: Pertaining to or characteristic of birds.

Barotrauma: Damage to tissue caused by rapid or excessive pressure changes.

Before-after/control-impact: A study design that involves comparisons of observational data, such as bird counts, before and after an environmental disturbance and in a disturbed and undisturbed site. This study design allows a researcher to assess the effects of constructing and operating a wind turbine by comparing data from the “control” sites (before and undisturbed) with the “treatment” sites (after and disturbed).

Buffer zone: Non-disturbance areas that provide a protected zone for sensitive resources such as raptor nests or bat roosts.

Corvid: A bird belonging to family Corvidae. California corvids include ravens, crows, jays, and magpies.

Cumulative impact: The effect on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseen future actions. Cumulative impacts result from individually minor but collectively significant actions taking place over a period of time.

Echolocation: The detection of an object by means of reflected sound. The animal emits a sound, usually at a very high frequency, which bounces off an object and returns as an echo. Interpreting the echo and the time taken for it to return allows the animal to determine the position, distance, and size of the object and thus helps the animal to orientate, navigate, and find food.

Feathering: A form of overspeed control for wind turbines that occurs either by rotating the individual blades to reduce their angle into the wind, thereby reducing rotor speed, or by turning the whole unit out of the wind. When rotors are feathered they are pitched parallel to the wind, essentially making them stationary.

Guy wire: Wires used to secure wind turbines or meteorological towers that are not self-supporting.

Habitat: The place where an animal or plant usually lives, often characterized by a dominant plant form or physical characteristic.

Incidental finds: Carcasses found by personnel at times other than the scheduled carcass search.

Indirect impact: Impacts that are caused by a project but occur at a different time or place (for example, displacement of local populations).

Large birds: Birds larger than 10 inches (25 centimeters) in length, as described in the *National Geographic Field Guide to the Birds of North America*.

Large-sized turbine: A wind turbine capable of generating 750 kW or more of electricity.

Lasiurine: Bats that belong to the genus *Lasionycteris*. In California lasiurine bats include the silver-haired bat (*Lasionycteris noctivagans*) and the western red bat (*Lasiurus blossevillei*).

Lattice design: A wind turbine design characterized by a structure with horizontal bars rather than a single pole supporting the nacelle and rotor.

Lead agency: The public agency that has the principal responsibility for carrying out or approving a project.

Lek: A lek is a gathering of males for the purposes of competitive mating displays. An example of a lekking species in California is the greater sage grouse, which occurs in northeastern and eastern portions of the state in Great Basin sagebrush habitat.

Macro-siting: The selection of large wind resource areas suitable for regional development.

Megawatt (MW): A measurement of electric-generating capacity equivalent to 1,000 kilowatts (kW) or 1,000,000 watts.

Micro-siting: Small-scale site selection for wind turbines, typically involving placement of turbines; involves locating the placement of turbines, roads, power lines, and other facilities.

Migration: Regular, extensive, seasonal movements of birds between their breeding regions and their "wintering" regions.

Migratory flyway: A broad geographical swath through which migratory birds travel seasonally between breeding grounds to wintering areas. California is within the Pacific Flyway, one of four major waterfowl flyways in North America.

Migratory route: Migration routes or corridors are the relatively predictable pathways that a migratory species travels between breeding and wintering grounds. Migratory routes are diverse and vary widely among species.

Monitoring: A continuous, ongoing process of project oversight. Monitoring, rather than simply reporting, is suited to projects with complex mitigation measures that may exceed the expertise of the local agency to oversee, that are expected to be implemented over a period of time, or that require careful implementation to assure compliance.

NEXRAD: A contraction of "Next-Generation Radar." It refers to a network of 158 high-resolution Doppler weather radars operated by the National Weather Service, an agency of the National Oceanic and Atmospheric Administration within the United States Department of Commerce. Its technical name is WSR-88D, which stands for Weather Surveillance Radar, 1988, Doppler. NEXRAD detects precipitation and atmospheric movement or wind, and allows researchers to record large-scale animal migration events and relate these to topography and local and regional weather conditions.

Parameter: A statistical term denoting a numerical characteristic about the population of interest.

Passerine: Describes birds that are members of the order Passeriformes, typically called "songbirds."

Phasianids: Birds classified in the family Phasianidae. Native California phasianids include birds such as the greater sage grouse, dusky grouse, and sooty grouse.

Population: A group of individuals in a particular location that are of the same species and can reproduce with each other.

Precision: The repeatability or reproducibility of a measurement, without respect to its correctness (accuracy).

Range: The distance between the highest and lowest score. Range is one of several indices of variability that statisticians use to characterize the dispersion among the measures in a given population.

Raptor: Pertaining to eagles, hawks, and owls; birds which are predatory, preying upon other animals.

Relative abundance: A percent measure or index of the abundances of individuals of all species in a community.

Renewable energy: Energy resources that do not get depleted because they renew themselves. Sources of renewable energy include solar, wind, geothermal, hydroelectric, and biomass.

Riparian: The vegetation, habitats, or ecosystems that are associated with streams, rivers, or lakes, or are dependent upon the existence of perennial, intermittent, or ephemeral surface or subsurface water drainage.

Rotor: The part of a wind turbine that interacts with wind to produce energy. It consists of the turbine's blades and the hub to which the blades attach.

Rotor-swept area: The vertical airspace within which the turbine blades rotate on a pivot point or drive train rotor.

Small birds: Birds 10 inches (25 centimeters) in length or smaller.

Small-sized turbine: A turbine that is capable of generating between 40 kW and 400 kW of electricity.

Songbird: A bird, especially one of the suborder Oscines of passerine birds, having a melodious song or call.

Special-status species: Animals or plants in California that belong to one or more of the following categories:

- Listed on California Department of Fish and Game's Special Animals List www.dfg.ca.gov/biogeodata/cnddb/pdfs/SPAnimals.pdf
- Officially listed or proposed for listing under the California and/or Federal Endangered Species Acts
- State or federal candidate for possible listing
- Taxa that meet the criteria for listing, even if not currently included on any list, as described in section 15380 of the California Environmental Quality Act Guidelines
- Taxa considered by the California Department of Fish and Game to be a Species of Special Concern
- Taxa that are biologically rare, very restricted in distribution, declining throughout their range or that have a critical, vulnerable stage in their life cycle that warrants monitoring
- Populations in California that may be on the periphery of a taxon's range, but are threatened with extirpation in California

- Taxa closely associated with a habitat that is declining in California at an alarming rate (for example, wetlands, riparian, old growth forests, desert aquatic systems, native grasslands, vernal pools, etc.)
- Taxa designated as a special-status, sensitive, or declining species by other state or federal agencies or non-governmental organizations

Strobe light: Light consisting of pulses (of light) that are high in intensity and short in duration.

Taxon: A classification or group of organisms (that is, kingdom, phylum, class, order, family, genus, species). Plural: taxa.

Tubular design: A turbine that is raised above the ground by a cylindrical structure.

Turbine: A device that uses steam, gas, water, or wind to turn a wheel, converting kinetic energy into mechanical energy in order to generate electricity.

Turbine height: The distance from the ground to the highest point reached by the blades of a wind turbine.

Wind resource area: The geographic area or footprint within which wind turbines are located and operated. The term may be used to describe an existing facility or a general area in which development of a facility is proposed.

Wind turbine: A machine for converting the kinetic energy in wind into mechanical energy, which is then converted to electricity.

APPENDIX A

INDIVIDUALS AND ORGANIZATIONS CONTACTED DURING ROADMAP DEVELOPMENT

NAME	AFFILIATION
Anderson, Dick	Consulting biologist
Arnett, Ed	Bat Conservation International
Bloom, Pete	Bloom Biological, Inc.
Estep, Jim	Estep Environmental Consulting
Flint, Scott	California Department of Fish and Game (CDFG)
Gann, Janice	CDFG
George, Garry	Los Angeles Audubon Society
Green, Mike	U.S. Fish and Wildlife Service
Guepel, Geoff	Point Reyes Bird Observatory Conservation Science
Hogan, Bronwyn	CDFG
LeMay, Brenda	Horizon Wind Energy
LePre, Larry	Bureau of Land Management
Levin, Julia	Audubon California
Linehan, Andy	PPM Energy
Marr, Jenny	CDFG
McMahon, Sara	PPM Energy
Newman, Jim	Pandion
Orloff, Sue	Ibis Consultants
Rader, Nancy	California Wind Energy Association
Sinclair, Karin	National Renewable Energy Laboratory
Smallwood, Shawn	Consulting biologist
Stein, Kenny	FPL Energy
Tenneboe, Annette	CDFG
Ugoretz, Steve	Wisconsin Department Natural Resources
Vance, Julie	CDFG
Vercruyssen, Paul	Center for Energy Efficiency and Renewable Technologies
Villegas Patraca, Rafael	Instituto de Ecologia AC, Veracruz, Mexico
Webb, Bruce	CDFG
Webster, Stu	Clipper Windpower, Inc.
Weller, Ted	USDA Forest Service
Warren-Hicks, Bill	EcoStat, Inc.
Wolfe, Marsha	M.H. Wolfe & Associates
Zichella, Carl	Sierra Club

APPENDIX B

SCIENTIFIC NAMES OF BIRDS AND MAMMALS MENTIONED IN TEXT

COMMON NAME	SCIENTIFIC NAME
BIRDS	
American kestrel	<i>Falco sparverius</i>
Bald eagle	<i>Haliaeetus leucocephalus</i>
Bobolink	<i>Dolichonyx oryzivorus</i>
Broad-winged hawk	<i>Buteo platypterus</i>
Burrowing owl	<i>Athene cunicularia</i>
Common raven	<i>Corvus corax</i>
Golden eagle	<i>Aquila chrysaetos</i>
Greater prairie chicken	<i>Tympanuchus cupido</i>
Greater sage grouse	<i>Centrocercus urophasianus</i>
Horned lark	<i>Eremophila alpestris</i>
Mississippi kite	<i>Ictinia mississippiensis</i>
Northern harriers	<i>Circus cyaneus</i>
Northern goshawk	<i>Accipiter gentilis</i>
Red-tailed hawk	<i>Buteo jamaicensis</i>
Red-winged blackbird	<i>Agelaius phoeniceus</i>
Sandhill crane	<i>Grus canadensis</i>
Swainson's hawk	<i>Buteo swainsonii</i>
Turkey vulture	<i>Cathartes aura</i>
Vesper sparrow	<i>Pooecetes gramineus</i>
Western meadowlark	<i>Sturnella neglecta</i>
MAMMALS	
Badger	<i>Taxidea taxus</i>
Big free-tailed bat	<i>Nyctinomops macrotis</i>
Eastern pipistrelle bat	<i>Pipistrellus subflavus</i>
Eastern red bat	<i>Lasiurus borealis</i>
Gopher	<i>Thomomys bottae</i>
Ground squirrel	<i>Spermophilus beecheyi</i>
Hoary bat	<i>Lasiurus cinereus</i>
Mastiff bat	<i>Eumops perotis</i>
Mexican free-tailed bat	<i>Tadarida brasiliensis</i>
Pocketed free-tailed bat	<i>Nyctinomops femorosaccus</i>
San Joaquin kit fox	<i>Vulpes macrotis mutica</i>
Silver haired bat	<i>Lasionycteris noctivagans</i>
Western red bat	<i>Lasiurus blossevillii</i>

